Aquaculture Practices in Irrigation Reservoirs of the Western Cape Province of South Africa in Relation to Multiple Resource Use and Socio-Ecological Interaction

By

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ABSTRACT

Aquaculture has proven to be a viable operation in multi-used irrigation reservoirs (also referred to as farm dams) in the Western Cape province (WCP) of South Africa. Many studies found that the fitness-for-use of these reservoirs for both net cage culture of fish and irrigation of crops is feasible. However, practising intensive fish farming in existing open water bodies can increase the nutrient levels of the water through organic loading, originating from uneaten feeds and fish metabolic wastes. Under such conditions the primary (irrigation) and secondary (drinking water and recreation) usage of the dam could be compromised by deteriorating water quality. Rainbow trout (*Oncorhynchus mykiss*) farming is done in Mediterranean climatic conditions of the WCP. This type of climate presents short production seasons with fluctuating water quality and quantity. The study investigated the dynamics of water physico-chemical parameters and assessed the long term impact of rainbow trout farming on irrigation reservoirs. Furthermore, associated land-use in the catchment of such integrated aqua-agriculture systems is described, and mitigation to minimise the impact of fish farming evaluated. The investigation concluded with assessing the contribution of aquaculture to rural and peri-urban communities. The aim is to present an integrated, socio-ecologically balanced farming system for irrigation reservoirs with associated aquaculture activities.

A total of 35 reservoirs, including both fish farming and non-fish farming ones, were selected as research sites. They were located in three geographical regions namely, Overberg (Grabouw/Caledon), Boland (Stellenbosch/Franschhoek) and Breede River (Ceres/Worcester). Reservoirs were <20 ha in surface area and the volume ranges from 300 000 to 1 500 000 m^3. Water samples were collected monthly and seasonally for the different investigations and analysed for a range of water quality parameters, including: transparency (Secchi disc), temperature, dissolved oxygen (DO), pH, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), chloride (Cl), carbonate (CO_3), bicarbonate (HCO_3), manganese (Mn), copper (Cu), zinc (Zn), boron (B), total phosphorous (TP), orthophosphate (PO_4), total ammonia nitrogen (TAN), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), aluminium (Al), total suspended solids (TSS), total dissolved solids (TDS), alkalinity, hardness and sulphate. Phytoplankton samples were also collected, genera identified and biomass calculated. The water quality data were analysed in terms of surface and bottom strata in both fish farming and non-fish farming reservoirs based on repeated measurements at the same site location at different times using the procedure General Linear Models of Stastical Analysis System (SAS, 2012). Values $p<0.05$ were considered as statistically significant. A Principal Component Analysis (PCA) biplot was used to graphically depict all the sites and measured water quality variables with the purpose of trying to see whether the fish farming and non-fish farming ones showed any groupings and how the sites were related to the measured variables. Structured questionnaires and informal discussions were used to collect additional information on the water use, production data and socio-economic effects on fish farmers. Categorical data gathered from the interviews (21 aquaculture projects) were analysed for frequency of occurrence using the Statistical Product and Service Solutions (SPSS) computer programme (SPSS Systems for Windows, Version 12.0). Results are presented in publication form with research chapters focusing on the subject areas of water quality impact, catchment land-use, potential mitigation measures and aquaculture contribution.

Results for the water quality analyses indicated that as a collective, the farm reservoirs' overall minimum,

mean and maximum values for the physico-chemical parameters were fit-for-use for trout farming. The depth of the reservoirs ranged from 1.2 - 21.6 m with the low value taken during the summer season. Values lower than 5.0 m can cause management problems for floating cages that require a minimum of 4.0 m for net suspension and 1.0 m of free space below for adequate lateral flow. The Secchi disc reading of the reservoirs ranged from 10 – 510 cm. Higher transparencies were recorded after the winter rains when sand, silt and clay settled. Trout feeding is dependent on visibility and transparencies of more than 50 cm are required for good feeding conditions. The dissolved oxygen (DO) ranged from 0.3 – 16.4 mg/L with values below 5.00 mg/L recorded during summer when extraction and temperatures were high and provided conditions unable to sustain trout farming. The situation reverses with the onset of winter when the dams fill and DO rises above 5.00 mg/L as required for trout farming. The phosphorous (P) levels ranged from 0.001 – 0.735 mg/L. Higher concentrations were recorded during the winter turnover phase when bottom and surface waters mixed. Concentration above 0.01 mg/L can cause eutrophication of the water bodies. Total ammonia nitrogen (TAN) ranged from 0.015 - 6.480 mg/L. Higher concentrations were recorded during summer when temperatures were high and depths were low. TAN can be toxic to fish when the pH and temperature are high.

The generally low least square means (LSM) for TAN were indicative of minor environmental impact of trout farming operations conducted during the colder, winter rainfall months. Trout farming coincided with conditions where the water temperatures were low, dam levels were high and dams were overflowing. The difference in bottom and surface water quality of reservoirs and the site location were found to be more important than the absence or presence of fish farming. The difference in bottom and surface water is directly linked to the ecological status of the sediment, which serve as nutrient sinks. In monomictic dams found in Mediterranean areas, mixing occurs during the winter turnover phase. Nutrients are released due to surface and bottom water mixing, brought about by torrential rains and wind turbulence. The concentration of organic material in the sediment and bottom waters is a function of the nutrient loading over time, irrespective whether the non-point sources were fish farming or agricultural activities and therefore it is difficult to partition causes and effects. In cases where reservoirs were already eutrophic due to past agricultural practices, implementing aquaculture could exacerbate the poor water quality status of the reservoir. There was a statistically significant difference between fish farming and non-fish farming for phosphorous, Secchi disc, total suspended solids and nitrite-nitrogen ($p<0.05$) and no statistically significant difference between fish farming and non-fish farming for dissolved oxygen, total ammonia nitrogen and nitrate-nitrogen ($p>0.05$). There was a statistically significant difference between surface and bottom waters for P and TAN ($p<0.05$). One reason for higher P and TAN concentrations in bottom waters is the accumulation of both in the sediment and subsequent release in the water column when the water mixes. A two-dimensional scatter plot was generated using the score for the first two principal components. The first two principal components accounts for 40 and 17 % of the total variance respectively, and the two groups of fish farming and non-fish farming did not separate well based on the first two principal components.

The occurrence and distribution of phytoplankton biomass fluctuated with dam water levels and nutrient concentrations. The prevailing phytoplankton communities are important to fish farmers for two reasons: 1. It leads to fluctuations in dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis). 2. It could lead to algal taint of fish flesh when geosmin-producing phytoplankton species are present. The frequency of occurrence indicated that the Group Chlorophyta (including genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, etc) had the most occurrences (n=371) with Chrysophyta (including genera, *Dinobryon, Mallomonas, Synura*, etc) the least (n=34). There was a statistically significant difference between genera occurrence and season ($p<0.05$). The geographical location of sites had no significance influence on the frequency of phytoplankton occurrence. There was no direct link between water quality and production yield ($p>0.05$). The fish yield of farms were linked mainly to the quality of fingerlings and the feed conversion ratio (FCR) achieved ($p<0.05$).

Land-use patterns in the catchment where fish farming dams were located have shown that the dams are multiple-used systems. The ecological integrity of the farm dam ecosystem is dependent on the base volume. The dam is primarily for irrigation and fish farming can be compromised when higher demand for water is required during the dry season. The dams receive about 20 % of its water from rainfall and the rest from runoffs. Farmers could not provide accurate extraction rates making it difficult to predict water levels for future fish production.

Four potential mitigation measures to reduce nutrient loading were described namely, feed management (quantity, frequency, type, etc.), feeding method (demand feeders, hand feeding), feed ingredients (formulation) and floating gardens. Both feed management procedures and demand feeders were evaluated as to the efficiency of reducing feed wastage and optimising FCR's. The small-scale fish farmers were producing approximately 6 tons and had an average FCR of 1.96:1 ± 1.15. If farmers could improve their FCR's by 0.1 (i.e. from 1.96 to 1.86), it would translate into a reduction of 100 kg feed for every ton of fish produced and result in 5% decrease in nutrient loading. The results of the water analysis and visual assessment of faecal length and colour showed no statistically significant difference between treatments for the guar-gum based binder ($p>0.05$). In addition, the level of binder did not influence digestibility of the experimental diets.

The floating garden study indicated that it was feasible to construct a low cost raft system that is easy to manage and can produce plant crops as a hydroponic system in conjunction with fish farming cages. The lettuces grown on farm dam water provided support for the premise that the water quality can be improved via extraction of nutrients for crop production. For the production of 3.5 kg/m^2 lettuce, a ratio of 1.09 plants/fish equal to 1.84 g feed/day/plant would reduce the accumulation of soluble nutrients around floating net cage farming system.

The socio-economic evaluation of the contribution of fish farming to the welfare of rural and peri-urban farming communities supported the notion that aquaculture can lead to the upliftment of participating communities. Seventy-one percent (71%) of the respondents indicated that their motivation for exploring aquaculture is to supply fish to the wholesale market in order to generate income. Sixty-one percent (61%) of the respondents conducted the sales themselves or co-opted family members to assist them. The contribution of aquaculture provided direct benefits through improvement in household income, subsistence food supply and skills development. Indirect benefits included providing an information hub for other emerging farmers, elevation of the fish farmer's status in the community through greater wealth and knowledge creation and promoting sector diversification through new products and technology. The three main constraints to the promotion and growth of aquaculture were listed as lack of government support, insufficient market intelligence and access, and limited choice in the availability of suitable candidate aquaculture species.

Irrigation reservoirs in the WCP have a history of enrichment through external sources supplying water via agricultural runoff (fertilisers and pesticides), catchment runoff (leaf litter and organic debris) and stormwater effluent (grey and black water). The incorporation of aquaculture into such dams adds extra nutrients to the water column and management is crucial to limit the nutrient loading and ensure environmental sustainability. Such an approach will ensure that commercial land-based crop farmers' irrigation regime and water distribution operations would not be negatively affected. Therefore future research needs should focus on; firstly the prevention and minimisation of pollution deriving from aquaculture through improved production management and technology transfer, secondly the monitoring and evaluation of the catchment ecosystem as a continuum with all the external factors affecting the ecology of farm dams and thirdly, evaluating the sediment processes and dynamics as sinks for nutrient accumulation.

UITTREKSEL

Akwakultuur het getoon dat dit ‘n lewensvatbare inisiatief is vir meerdoelige-gebruik van besproeiingsdamme (ook genoem plaasdamme) in die Wes-Kaap provinsie (WKP) van Suid-Afrika. Vele studies het bewys dat die geskiktheid-vir-gebruik van die reservoirs haalbaar is vir beide visproduksie sowel as besproeiing van landbougewasse. Nieteenstaande, die beoefening van intensiewe visboerdery in bestaande buitelug watersisteme kan lei tot ‘n toename in nutriëntvlakke van die water as gevolg van organiese belading afkomstig van ongevrete voere en metaboliese afvalstowwe van die vis. Onder sulke omstandigthede kan die primêre- (besproeiing) en die sekondêre (drinkwater en rekreasie) gebruik van die dam in gedrang kom weens ‘n afname in waterkwaliteit. Reënboogforel (*Oncorhynchus mykiss*) boerdery word beoefen in die omliggende Mediterreense klimaat van die WKP. Die tipe klimaat verskaf kort produksie-seisoene met wisselvallige water kwaliteit en kwantiteit. Die studie het die dinamika van water se fisies-chemiese parameters ondersoek en het die impak van forelboerdery op besproeiingdamme oor die langtermyn beskryf. Verder het die studie die geassosieerde landgebruik in die opvangsgebied met geïntegreerde akwa-landbou sisteme beskryf, asook moontlike toetrede (mitigasie maatreëls) geëvalueer wat die impak moontlik kan verlaag. Die ondersoek is afgesluit deur die bydrae wat akwakultuur lewer aan landelike en semi-stedelike gebiede, te beskryf. Die hoofdoel is die daarstelling van ‘n geïntegreerde, sosio-ekologiese gebalanseerde sisteem vir besproeiingdamme met gesamentlike akwakultuuraktiwiteite.

‘n Totaal van 35 besproeiingsdamme, insluitend die met visboerdery en nie-visboerdery, is gekies as navorsingspersele. Dit is hoofsaaklik geleë in drie geografiese gebiede naamlik, Overberg (Grabouw/Caledon), Boland (Stellenbosch/Franschhoek) en Breederivier (Ceres/Worcester). Die reservoirs is almal < 20 ha in oppervlakarea en die volumes het gewissel van 300 000 – 1 500 000 m^3. Watermonsters is maandeliks sowel as seisoenaal versamel vir die onderskeie ondersoeke en ontleed vir ‘n reeks van parameters, insluitend: sigbaarheid (Secchi disc), temperatuur, opgeloste suurstof (OS), pH, natrium (Na), kalium (K), kalsium (Ca), magnesium (Mg), yster (Fe), chloor (Cl), karbonaat (CO_3), bikarbonaat (HCO_3), mangaan (Mn), koper (Cu), sink (Zn), boor (B), totale fosfor (TP), ortofosfaat (PO_4), totale ammoniak stikstof (TAN), nitraat-stikstof (NO_3-N), nitriet-stikstof (NO_2-N), aluminium (Al), totale gesuspendeerde vaste stowwe (TGV), totale opgeloste vaste stowwe (TOV), alkaliniteit, hardheid en sulfate. Phytoplanktonmonsters is ook versamel, genera geïdentifiseer en die biomassa bepaal. Die waterkwaliteitsdata is ontleed in terme van oppervlak- en bodemstrata vir beide visboerdery en nie-visboerdery reservoirs en was gebaseer op herhaalde metings by dieselfde perseel op verskillende tye deur gebruik te maak van die Algemene Liniêre Model van Statistiese Analitiese Sisteem (SAS, 2012). Waardes $p<0.05$ is oorweeg as statisties beduidend. ‘n Hoofkomponentanalise bi-stipping (HKA) is toegepas om die persele en veranderlikes grafies voor te stel en te bepaal of die visboerdery en nie-visboerdery s’n enige groeperinge vorm asook hoe die persele assosieer met die veranderlikes. Gestruktureerde vraelyste en informele besprekings is onderneem om inligting in te samel op watergebruik, produksie-data, en die sosio-ekonomiese invloed wat akwakultuur bied aan visboere. Kategoriese data wat deur die onderhoude (21 akwakultuurprojekte) ingesamel is, is ontleed vir die frekwensie van aanwesigheid deur die gebruik van Statistiese Produk en Dienste-oplossings (SPDO) rekenaarprogram (SPSS Systems for Windows, Version 12.0). Die resultate vir die verskeie ondersoeke is beskryf en saamgestel in publikasie-vorm met die navorsingshoofstukke wat gefokus het op die areas van waterkwaliteitsimpak, opvangsgebied landgebruik, toetrede-meganismes en die bydrae van akwakultuur.

Die resultate vir die waterkwaliteitsanalises het getoon dat gesamentlik die reservoirs se oorhoofse minimum, gemiddelde en maksimum waardes vir die verskillende fisies-chemiese parameters geskik is vir forelboerdery. Die diepte van die reservoirs het gewissel van 1.2 - 21.6 m, met die laagste waarde aangeteken gedurende die somermaande. Waardes laer as 5.0 m kan bestuursprobleme vir drywende hokstelsels versoorsaak want 'n minimum van tenminste 4.0 m vrye spasie onder die hokke word benodig vir voldoende laterale vloei. Die Secchi-skyf lesing (sigbaarheid) van die reservoirs het gewissel van 10 – 510 cm. Hoër sigbaarheidswaardes is aangeteken na winterreëns wanneer sand-, slik- en klei deeltjies uitgesak het. Forel voer op sig en sigbaarheid van > 50 cm word benodig om goeie voeding te handhaaf. Die OS het gewissel van 0.3 – 16.4 mg/L met waardes onder 5 mg/L aangeteken gedurende somer wanneer wateronttrekking en temperature hoog was. Dit het gelei tot ongunstige toestande vir forelboerdery. Die situasie swaai om met die begin van winter wanneer die damme vol reën en die OS bo 5 mg/L styg soos benodig vir forelboerdery. Die P-vlakke het gewissel van 0.001 – 0.735 mg/L. Hoër waardes is aangeteken gedurende die winteromkeerfase wanneer die bodem en oppervlak se water meng. Konsentrasies bo 0.01 mg/L kan tot eutrofikasie van watersisteme lei. TAS het gewissel van 0-015 – 6.480 mg/L. Hoër konsentrasies is aangeteken gedurende die somer wanneer temperature hoog is en damvlakke laag. By hoë pH's en temperature kan TAS toksies wees vir vis.

The algemene lae kleinste kwadaat gemiddelde (KKG) waarde vir TAS het getoon dat daar 'n klein impak op die omgewing was wanneer forelboerdery bedryf word gedurende die koue, winter reënvalmaande. Forelboerdery val saam met omstandigthede wanneer die watertemperature laag is, damvlakke hoog en die reservoirs oorloop. Die verskil in die bodem- en oppervlak water in die besproeiingsdamme en die ligging van die perseel is vasgestel om meer belangrik te wees as die teenwoordigheid of afwesigheid van visboerdery. Die verskil in die bodem en oppervlak is toe te skryf aan die toestand van die sediment waar nutriënte kan opgaar. In monomiktiese damme soos gevind in Mediterreende areas, vind vermenging plaas gedurende die winteromkeerfase. Nutriënte word vrygestel a.g.v. die vermenging van die oppervlak en bodem se water wat dan veroorsaak word deur harde reën en windturbulensie. Die konsentrasie van organiese materiaal in die sediment en bodem water is 'n funksie van die nutriëntlading met tyd, ongeag of dit afkomstig was vanaf visboerdery of landbou-aktiwiteite. Dit is dus moelik om die spesifieke oorsaak van besoedeling af te baken. In gevalle waar die reservoirs alreeds eutrofies is a.g.v. aangewese landbou-aktiwiteite, kan die toestand van die waterbron vererger indien akwakultuur toegepas word. Daar is 'n statistiese noemenswaardige verskil tussen visboerdery en nie-visboerdery vir P, Secchi-skyf, totale gesuspendeerde vaste stowwe en nitrite-stikstof ($p<0.05$), en geen statistiese noemenswaardige verskil tussen visboerdery en nie-visboerdery vir OS, TAS en nitraat-stikstof ($p>0.05$). Daar is 'n statistiese noemenswaardige verskil tussen oppervlak- en bodem water vir P en TAS ($p<0.05$). Een moontlike rede vir hoër P en TAS konsentrasies in die bodemwater, is die akkumulasie van beide parameters in die sediment en gevolglike vrystelling in die waterkolom wanneer die water gemeng word. 'n Twee dimensionele spreidingstipping is geprodueer deur die waardes te gebruik van die eerste twee hoofkomponente. Die eerste twee hoofkomponente dra by 40 % en 17 % van die totale variansie onderskeidelik, en die twee groepering van visboerdery en nie-visboerdery het nie duidelik getoon nie.

Die voorkoms en verspreiding van phytoplankton biomassa het gewissel met die verandering in damvlakke en nutriëntkonsentrasies. Die aanwesige phytoplanktongemeenskappe is belangrik vir die visboer vir twee redes: 1. Dit kan wisselende OS-vlakke versoorsaak deur die verbruik (respirasie en dekomposisie) en produksie (fotosintese) daarvan. 2. Dit kan lei tot alge na-smake van vis wanneer geosmin-produserende phytoplankton spesies aanwesig is. The frekwensie van voorkoms het getoon dat die Groep Chlorophyta (insluitend die genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, ens.) die meeste voorkom (*n*=371), met Chrysophyta (insluitend die genera, *Dinobryon, Mallomonas, Synura*, ens.) die minste (*n*=34). Daar is 'n statistiese noemenswaardige verskil tussen genera voorkoms en seisoen ($p<0.05$) vir phytoplankton. Die geografiese ligging van die perseel het geen noemenswaardige invloed op die frekwensie van phytoplankton voorkoms nie. Daar is geen statistiese noemenswaardige verbintenis tussen waterkwaliteit en visproduksieopbrengste nie ($p>0.05$). Die visopbrengste by plase is hofsaaklik afhangende van die kwaliteit van die vingerlinge en die voeromsettingsverhouding (VOV) wat bereik is ($p<0.05$).

Die landgebruikspatrone in die opvangsgebied waar visboere gesetel is, het aangedui dat die besproeiingsdamme meeldoelige sisteme is. Die ekologiese integriteit van die plaasdam-ekosisteem is afhanklik van die basisvolume. Die dam is hoofsaaklik daar vir die besproeiing en visboerdery kan in gedrang kom wanneer daar 'n hoër aanvraag vir water gedurende die droë seisoen is. Die damme het omtrent 20 % van die water vanaf reënval ontvang en die res van aflope. Boere kon nie akkurate inligting verskaf van waterontrekking nie wat dit moeilik gemaak het om te voorspel wat die beskikbare watervlakke in die toekoms sou wees vir visproduksie.

Vier potensiële toetrede meganismes om die nutriëntlading te verminder, is beskryf naamlik voedingsbestuur, (kwantiteit, frekwensie, tipe, ens.) voermetodes (aanvraagvoeder, handvoeding), voerbestandele (formulasies) en drywende tuine. Beide voedingsbestuur prosedure en aanvraagvoeders is geëvalueer as 'n metode om die voervermorsing te verminder en die VOV te verbeter. Die kleinskaalse visboere het ongeveer 6 ton produseer met 'n gemiddelde VOV van 1.96:1 ± 1.15. Indien die visboere hul VOV's met 0.1 kan verbeter (bv. van 1.96 tot 1.86), sal dit beteken dat daar 'n vermindering van 100 kg voer bewerkstellig word vir elke ton vis geproduseer. Dit kan ook lei tot 'n vermindering van 5 % in die nutriëntlading. Die resultate van die wateranalises en die visuele waarneming van faeceslengte en kleur het geen statistiese noemenswaardige verskil tussen die behandelinge vir die guar-gom binder getoon nie ($p>0.05$). Verder, die hoeveelheid van die binder het nie die vertering van die eksperimentele diëte beïnvloed nie.

Die studie op die drywende tuine het getoon dat dit haalbaar is om 'n lae-koste sisteem te bou wat maklik is om te bestuur en gewasse kan produseer soos in 'n hidroponiese sisteem tesame met visproduserende hokstelsels. Die kropslaaie se groei het getoon dat die waterkwaliteit van besproeiingsdamme kan verbeter word deur die opname van nutriënte wanneer plante verbou word. Vir die produksie van 3.5 kg/m^2 kropslaaie, sal 'n verhouding van 1.09 plante/vis of 1.84 g voer/dag/plant die akkumulasie van opgeloste nutriënte rondom die hokstelsels verminder.

Die sosio-ekonomiese evaluasie van die bydrae van visboerdery tot die welvaart van die landelike en semi-stedelike plaasgemeenskappe ondersteun die feit dat akwakultuur verbetering kan bewerkstellig, veral onder deelnemende gemeenskappe. Een-en sewentig persent (71 %) van die respondente het getoon dat hul oorweging vir die bedryf van akwakultuur is om vis te voorsien aan die grootmark en daarvolgens geld te maak. Een-en-sestig persent (61 %) van die respondente het aangedui dat hulself die vis verkoop of vir familie-lede vra om met die verkope te help. Die bydrae van akwakultuur het direkte voordele aan die deelmers voorsien deur ‘n verbetering in huishoudelike inkomste, voedselvoorsiening vir selfgebruik en die ontwikkeling van vaardigthede. Indirekte voordele sluit in dat die deelmers ‘n bron van inligting geword het vir opkomende boere, hul status in die gemeenskap het verbeter omdat hul kennis verbreed het en dit het verder gelei tot diversifisering in die sektor a.g.v. die skepping van nuwe produkte en tegnologie. Die drie hoof struikelblokke wat die groei en bevordering van akwakultuur belemmer is o.a., ‘n tekort aan staatsondersteuning, onvoldoende markinligting en toegang en ‘n beperkte keuse in spesies vir boerdery.

Besproeiingsdamme in die WKP het ‘n geskiedenis van verryking deur eksterne bronne wat water voorsien vanaf landbou-afloop (bemestingstowwe en pesbestrydingsmiddels), opvangsgebied-afloop (blare en ander organiese debris) en stormwateruitlaat (gruis- en swart water). Die implementering van akwakultuur in sulke damme voeg addisionele nutriënte tot die waterkolom en bestuur is krities om die lading te verminder en te verseker dat omgewingsvolhoubaarheid behou word. Indien die regte praktyke en bestuur toegepas word, sal dit beteken dat die kommersiële boer se besproeiing en waterverspreiding nie negatief beïnvloed word nie.

Vervolgens moet toekomstige navosingsbehoeftes fokus op eerstens, die voorkoming en vemindering van besoedeling afkomstig van akwakultuur deur verbeterde produksie-bestuur en tegnologie-oordrag, tweedens, die monitoring en evaluering van die opvangs-ekosisteem as ‘n kontinuum met al die eksterne faktore wat die ekologie van die plaasdam kan beïnvloed en laastens, die ondersoek en evaluering van die sediment se prosesse en dinamika as ‘n sisteem wat nutriënte ophoop.

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APPENDICES

LIST OF ACRONYMS

ANOVA	Analysis of Variance
ASCE	American Society of Civil Engineers
BEMLAB	Private analysis Laboratory, situated in Somerset West
BOD	Biological Oxygen Demand
DAFF	Department of Fisheries and Forestry (formerly DWAF)
DEAT	Department of Environmental Affairs and Tourism
DO	Dissolved Oxygen
DST	Department of Science and Technology
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FCR	Food Conversion Ratio
HACH	Company that manufactures and distributes analytical instruments and reagents used to test the quality of water and other aqueous solutions
IDPH	Illinois Department of Public Works
LSM	Least Square Means
NPS	Non-point source
NSP	Non-starch polysaccharides
SAS	Statistical Analysis System
SAWS	South African Weather Service
SGR	Specific Growth Rate

SOFIA	The State of World Fisheries and Aquaculture
TAN	Total Ammonia Nitrogen
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

GLOSSARY

Ad libitum

A duty performed freely or at the discretion of the performer here pertaining to feeding of fish.

Allogenic and Autogenic

Successional change can be caused by either endogenous or exogenous factors. If the change is caused by endogenous factors (within the organism itself) it is termed autogenic. In cases where the changes are caused by exogenous factors (external factors), it is termed allogenic.

Alkalinity

Alkalinity is a measure of the presence of bicarbonate, carbonate or hydroxide constituents. Concentrations less than 100 mg/L are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400 mg/L. A minimum level of alkalinity is desirable because it is considered a “buffer” that prevents large variations in pH. High alkalinity (above 500 mg/L) is usually associated with high pH values and consequent hardness.

Ammonia

Ammonia is a pungent, colourless highly soluble gas mainly used in the manufacture of fertilizers, nitric acid and other nitrogenous compounds. The chemical formula is NH_3. The term ammonia refers to two chemical species which are in equilibrium in water (NH_3, un-ionized and NH_4^+, ionized). Tests for ammonia usually measure total ammonia (NH_3 plus NH_4^+). In general, more NH_3 and greater toxicity exist at higher pH and temperature. Of the two, the free ammonia form is considerably more toxic to organisms such as fish. Free ammonia is a gaseous chemical, whereas the NH_4^+ form of reduced nitrogen is an ionized form which remains soluble in water.

Anoxia

It refers to very low or absence of oxygen. In most farm dams the water is relatively stagnant or stationary. However, huge water movement usually occurs when the dam overflows or during extraction for irrigation. The hypolimnium is the anoxic layer (due to decomposition of accumulated organic material resulting in lack of mixing).

Aquafeeds

It is short for aquaculture feeds and refers to the manufacturing of aquatic species specific diets based on a ration of ingredients that are utilised cost-effectively and provide for the optimal growth rates with minimal environmental impact.

Aquaponics

It is an integrated aquaculture (growing fish) and hydroponic (growing plants without soil) system that mutually benefits both environments.

Biological Oxygen Demand (BOD)

This is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down (oxidate) organic matter.

Cages

Cages are floating structures with suspended net cages forming enclosures to house aquatic organisms.

Catchment Area

Catchment describes the area from which surface runoff is carried away by a single drainage system (river, basin or dam).

Dam (Reservoir)

A dam is a barrier constructed across a waterway (to control the flow or raise the level of water or the body of water that is contained by such a barrier). Another term for reservoir would be dam. In South Africa, small farm dams mostly serve the purpose of storing water for irrigation or drinking supply.

Epilimnion

This is the layer of water at the surface of the reservoir occurring above the deeper hypolimnion. It is warmer and typically has a higher pH and dissolved oxygen concentration compared to the hypolimnion. Being exposed at the surface, it typically becomes turbulently mixed as a result of surface wind-mixing. It is also able to exchange dissolved gases (O_2 and CO_2) with the atmosphere.

Eutrophication

This refers to the enrichment of a water body with chemical compounds through non-point sources such as agricultural runoff, industrial and household effluent and stormwater. Eutrophication is a natural phenomenon and can be exacerbated by anthropogenic activities.

Food Conversion Ratio (FCR)

The FCR is generally expressed as the ratio of feed mass input to body mass output over a specified period of time.

Google Earth

Google Earth is a virtual globe map and geographical information programme which maps the Earth by the superimposition of images obtained from satellite imagery aerial photography and GIS 3D globe.

Hardness

Hard water is high in dissolved minerals such as magnesium and calcium.

Holomictic

The term holomictic refers to the mixing regime of a water body. A holomictic lake or dam is completely mixed during a turnover event, whereas in some very deep lakes, the deepest layer might not be involved in the mixing (meromictic). Most water bodies are holomictic.

Hypolimnion

The layer of water in a thermally stratified reservoir that lies below the thermocline, is usually non-circulating, and can remain perpetually cold. Being at depth, the hypolimnion is isolated from surface wind-mixing, and usually receives insufficient radiance (light) to enable photosynthesis and oxygen exchange. The layer is characterised by high concentrations of carbon dioxide, ammonia and hydrogen sulphide, as well as low or no DO concentrations.

Mitigation

Mitigation refers to the dentification and structuring of appropriate measures and plans to reduce or manage potential environmental impacts within acceptable standards. Such measures can be structural (i.e. engineering) or non-structural (training).

Monomictic

Monomictic reservoirs mix from top to bottom during one mixing period each year. Such reservoirs usually become destratified during the mixing event. In Mediterranean and subtropical regions, the temperatures of epilimnion and hypolimnion are isothermal (of the same temperature) in winter, so that there is only one mixing phase per year, lasting from two to several months.

Non-point source

Non-point source pollution to water bodies generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification.

Phytoplankton

Phytoplanktons are photosynthesizing free-floating microscopic organisms that inhabit the upper sunlit layer of almost all bodies of fresh water. There are mostly autotrophic (photosynthetic) organisms in aquatic systems.

Poikilothermic

The organism’s internal temperature varies according to the temperature of the surroundings.

Polyculture

Polyculture refers to the association of fish species of different food habits (feeding at different trophic levels) for the effective use of available fish foods in the pond, where wastes produced by one species may be inputs for other species.

Ponds

Land-based rectangular dug-outs, also called earthen ponds. They can also comprise circular water containers constructed in series or parallel with water flowing through the system or recycled. Ponds are commonly constructed along a gradient where water is supply to the production systems via gravity.

Pycnocline

A pycnocline is a layer in a body of water where the density of algae is the greatest.

Raceways

Rectangular water containers constructed in series either as in earthen dams or plastic/concrete containers with water flowing through the system.

Recirculation systems

It generally uses cement or plastic containers where the water is re-used through a closed flow system.

Resilience

This is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and identity.

Runoff

Surface runoff is the water flow that occurs when the soil is infiltrated to full capacity and excess water from rain or other sources flows over the land to a collecting structure such as dams. Included are not only the waters that travel over the land surface and through channels to reach a dam but also interflow, the water that infiltrates the soil surface and travels by means of gravity toward a stream channel (always above the main groundwater level) and eventually empties into the dam. Runoff also refers to groundwater that is discharged into a stream. The total runoff is equal to the total precipitation less the losses caused by evapotranspiration (loss to the atmosphere from soil surfaces and plant leaves), storage (as in temporary dams), and other such abstractions.

Secchi disk

A Secchi disk is usually a 20 cm diameter disk with alternating black and white quadrants. It is lowered into the water until the observer cannot differentiate between the lighter and darker colouring. This depth at which this differentiation is nullfied is called the Secchi depth and it is a measure of the transparency of the water.

Shoreline

Indicates the edge of a body of water e.g. a dam. The shoreline distance is usually calculated when dams are full to capacity.

Specific Growth Rate (SGR)

The rate at which fish grow is dependent on a number of factors including species, age, genetic potential, water temperature, health, and quantity and quality of food. The simplest modes for fish growth can be obtained by saying that all newly laid-down tissue is itself capable of equal growth thereby producing an exponential growth curve. However, this only holds true if the percentage of body weight gained per unit time remains constant throughout the life of the fish. This is not the case - young fish are capable of doubling their weight in a much shorter time than when they are older due to a decrease in potential growth rates. It is therefore useful to be able to ascertain the rate at which fish are growing by referring to the instantaneous growth rate which is based on the natural logarithm of body weight. The formula most commonly used to express fish growth is indicated below (Steven et al., 2006).

SGR = (In FBW – in IBW) / D

where, FBW is the final body weight (g), IBW is the initial body weight (g) and D = no of days

Stagnation Phase/Stratification

In Mediterranean and subtropical climates, a thermocline develops during the summer months and divides the upper water layer (epilimnion) from the lower water layer (hypolimnion). Due to reduced water exchange by prevented mixture of water, this phase is called the stagnation phase and it can be associated with lower levels of dissolved oxygen.

Total Dissolved Solids (TDS)

A test for TDS includes the measurement of inorganic salts, organic matter and minerals. The solids can be iron, chlorides, sulphates, calcium or other minerals found on the earth's surface. The dissolved minerals can produce an unpleasant taste or appearance and can contribute to scale deposits on piping and conduits in aquaculture production systems.

<500 mg/L	Satisfactory
501 to 1000 mg/L	Less than satisfactory
1001 to 1500 mg/L	Undesirable
>1500 mg/L	Unsatisfactory

Total Suspended Solids (TSS)

Total suspended solids (TSS) include both suspended sediment and organic material collected with the water sample. Suspended solids in water reduce light penetration in the water column, can clog the gills of fish and invertebrates, and are often associated with toxic contaminants because organics and metals tend to bind to particles (e.g. phosphorus, bacteria). They also cause the build-up of sediments in water bodies and can lead to anoxic conditions in the bottom waters of farm dams.

Turnover Phase / Destratification Phase

Mixing in lakes and reservoirs is largely controlled by stratification. Stratification reduces vertical exchange and can drive horizontal exchange by enforcing a preferred vertical structure. During the winter months the temperature in the Western Cape province's water bodies tends to be similar throughout the whole water body and the whole water body (depending on overall depth) can undergo mixing.

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CHAPTER 1: Rational for the investigation of the impact of aquaculture on irrigation reservoirs

1.1 General Introduction

The use of irrigation dams for cage fish culture lture is not a new concept, internationally or in South Africa. This practice is becoming increasingly widespread and represents a farming system that can alleviate the pressure on the demand for primary water usage and increase the productivity of dams. Nationally, the total storage capacity of major reservoirs in South Africa currently amounts to about 33 900 million m^3, which is equal to approximately 70% of the mean annual runoff from the land surface of the country. This storage has been created by the construction of 252 large dams. In addition, some 3 500 dams with a height greater than 5 m have been registered with the Department of Water Affair's Dam Safety Office. The Western Cape province is an important agricultural area in South Africa and has a history of more than 350 years of manipulated commercial agriculture. The first constructed masonry dam is the Woodhead Dam under Table Mountain which was completed in 1897 (ASCE, 2012). This scenario led to the development of a network of storage dams for the drier season irrigation of agricultural crops. Aquaculture is a non-consumptive use of water and therefore these dams present good potential for the implementation of cage culture operations. This is particularly important where access to primary water resources for aquaculture is limited. Therefore the single most important environmental limiting factor for freshwater aquaculture development in South Africa is the lack of suitable freshwater resources (DWAF, 1996).

South Africa is mostly a semi-arid country with an average rainfall of only 450 mm per annum compared to the world average of about 860mm (DWAF, 2004). Predicted climatic changes for the Western Cape will result in an even worse scenario as rainfall is expected to decrease and temperatures are expected to rise (SAWS, 2007). The utilization of land and water resources for livelihood creation forms an integral part of the cultural and economic lives of coastal and inland communities in South Africa. Such utilization is based on tradition and to a large extent survival strategies brought about by the socio-economic situation in South Africa. Planning for the future water needs of the country is a complex task and strategies have to be derived to address the two key areas of water resource management and water demand management (Grobicki & Cohen, 1999). Such strategies have to be environment specific, low risk, eco-friendly and have to be sustainable with respect to time- and resource usage in order to conserve and enrich the aquatic natural capital. With increasing industrial development, the demand on the country’s water is nearing the point where conventional supplies for human use will soon be exceeded. Due to increasing demand, utilisation has created more potential sources of pollutants to the water. As it stands, most of South Africa’s major rivers have been dammed to provide water for the growing population. In some areas over 50% of the wetlands have been converted for other land-use purposes; industrial and domestic effluent are polluting the ground- and surface waters, and changes in habitat have affected the biotic diversity of freshwater ecosystems (DEAT, 1999).

Eutrophication is a serious problem in a number of catchment areas in South Africa. This phenomenon can be directly linked to nutrient enrichment in freshwater resources and therefore the most important management approach involves minimising the influx of nutrients into receiving waters (Van Ginkel, 2011). Aquaculture in the form of fish farming can contribute to eutrophication through the accumulation of unutilized feed and excretory products in dissolved and solid form dispersed in the water column and accumulating in the bottom sediment. The challenge is to manage fish farming operations within the target range that will maintain the water quality requirements for crop irrigation and other usage, including recreational and drinking water. Apart from any potentially negative impact of fish farming on the environment, cognizance has to be taken of the potentially positive impact as well. Boyd & Salie (2011) postulated that where irrigation is the main purpose of the dam, enrichment can be beneficial for crop fertilisation. Earlier researchers (Maleri, 2008; Salie et al., 2008) conducted various research projects on the viability of tilapia and rainbow trout production in irrigation dams in the Western Cape province. Other countries, such as Pakistan and Iran, indicated similar studies on successfully cultured rainbow trout in cages (Kayim et al., 2007; Moogouei et al., 2010), whilst Turkey and Iran illustrated the interaction of the producing trout in cages with changes in water quality (Alpaslan & Pulatsü, 2008).

The production potential of any fish water body, including irrigation dams, is determined by a number of factors such as species of fish (in monoculture or polyculture), the water environment (water quality, oxygen levels, microbiological load, etc.) and the stocking density of the production system. Other factors such as feed quality and management are also important to consider. The effect of cage fish farming on the water quality in the storage structure was investigated in several studies (Cornel & Whoriskey, 1993; Pulatsu et al., 2004; Kayim et al., 2007; Du Plessis 2007, Maleri et al., 2008; Moogouei et al., 2010; Maleri 2011; Mirrasooli et al., 2012) and it was concluded that bio-geochemical enrichment is occurring, specifically with regard to the increasing concentration of the nitrogenous and phosphorous compounds. Of all the research conducted to date in South Africa, none of the investigations included adequate descriptions of the socio-ecological interaction within the agriculture-aquaculture landscape and its surrounding environment. An understanding of such dynamics could help development authorities decide on whether or not to include aquaculture on irrigation dams as a priority farming system to contribute to resource management and sustainable utilization. The aquaculture-agriculture is a dynamic system with different internal and external factors contributing to the ecological balance. Appendix 1 shows an organogram depicting the interaction of biotic and abiotic factors in an aquaculture system. An ecologically balanced farming system in irrigation dams will provide viable fish farming operations and simultaneously maintain ecological integrity of the water resource. Therefore it is important to understand the dynamics associated with fish farming systems on irrigation dams.

1.2 Motivation for this study

The motivation for this study is embedded in the need to continue and extend the research programme on the assessment of the interaction between cage aquaculture and water quality of irrigation reservoirs (Du Plessis, 2007; Maleri et al., 2008). Recent research programmes established the agenda and protocol to conduct monitoring and evaluation schedules to provide baseline data on the impact of aquaculture on open water systems, in particular storage dams for irrigation. Studies on the effect of aquaculture on the water quality and the fitness-for-use have to be conducted to ensure environmental integrity (Maleri, 2011).

Aquaculture provides a unique opportunity to contribute towards socio-economic development, food security and human resource development, through multiple and sustainable utilization of water resources, both for rural and peri-urban communities in South Africa (Brink, 2003; Rana et al., 2005). Such development is dependent upon the sustainable utilization of the available resources within the prevailing climate (Boyd et al., 2002). An opportunity has been identified for the integration of aquaculture into existing agricultural development without an increased consumptive demand on water resources, whilst limiting the impact on water quality through best management practices for all users (Salie et al., 1998). At present, with the global emphasis on sustainable development, particularly in the agricultural sector, more effort is being put into optimising resource use rather than exploiting new resources. Due to the nature of operation of floating net cage aquaculture systems, they allow the discharge of waste such as uneaten food, faeces, fish scales, mucus and organic soluble waste, directly in to the surrounding water environment (Stirling & Dey, 1990). During cage aquaculture the cultured species are confined, but organic and soluble wastes fall from the cages and mixes with the water column and sediment (Cornel & Whoriskey, 1993; Beveridge, 1996). Critical concepts that were described in the previous research included timing and implications of turnover phases, water retention times and the self-cleansing ability of the dams (Callebaut, 2000; De Groeve, 2003; Maleri et al., 2008; Maleri, 2011). Furthermore, feeding management is an important challenge facing small-scale farming aquaculture from a cost-optimization and water quality management point of view. In spite of general improvement in feed formulations, poor feeding practices pose an even bigger threat to economic and environmental sustainability of aquaculture practices. Various attempts are directed towards achieving more responsible aquafeeds and feed management practices (De Wet, 2007). Therefore, the current emphasis of the study is focused on long term sustainability of aquaculture in irrigation dams and interventions to enhance the viability of small-scale fish farming enterprises and related livelihood opportunities.

While previous research initiatives have given a detailed description of the expected impact of fish faming on water quality and proposals were also made regarding guidelines for biological and economic sustainability, the need exists to investigate the socio-ecological interaction and provide information based on a multi-ecosystem's approach. It is envisaged that the outcomes of the study will complement previous work and direct strategic decision making in relation to farm dam utilization and management. Further it will increase our knowledge base and enhance our understanding of integrated water resource management.

1.3 Objectives of the study

The broader objectives of the study were consolidated with:

- An overview of relevant literature in order to identify areas to be complemented with additional information and to formalize the research questions to address issues related to these areas.
- An evaluation of water ecology through describing and critically discussing the physico-chemical quality parameters of associated reservoirs with fish farming and those without.
- An interpretation of the chemical, biological and physical properties of catchments and the dynamics and interaction of land users in such ecosystems that increases water's productivity and perceived value.
- Undertaking a field study, complemented by literature, on potential mitigating measures (including management, mechanical devices and biological integrated systems) for farmers to minimize aquaculture waste.
- An investigation on the contribution of aquaculture to livelihood strategies of peri-urban and rural communities and achieving concurrent conservation of valuable resources through sustainable development.

1.4 Description of the approach used to address the objectives

Chapter 1 provides an overview and background setting for the study. The review of aquaculture practices (**Chapter 2**) provides information on the interaction of aquaculture and agriculture in irrigation dams to facilitate a multi-resource utilization system. The fieldwork conducted to quantify the environmental impact was spread across three geographical regions in the Western Cape province, namely Overberg (Grabouw/Caledon), Boland (Stellenbosch/Paarl) and Breede River (Ceres/Worcester). The sampling was performed from June 2008 until August 2011. Phytoplankton was also included and evaluated for frequency of occurrence, dominant classes and interdependence. Furthermore fish production data for the year 2009 were evaluated to determine the relationship between water quality parameters and production data. The results of the field work are described in **Chapter 3**.

The land-use changes in catchments where irrigation dams are located are described in **Chapter 4**, along with the discussion of the interaction of multiple water use ecosystems. The approach to describe feasible mitigation to reduce organic pollution is discussed in **Chapter 5**. Mitigation measures such as improved feed manufacturing and management, use of demand feeders and integrated plant-fish systems were investigated. The role and function of freshwater aquaculture in rural and peri-urban farming communities is described in **Chapter 6**. For this study information was collected via structured questionnaires and informal discussions from a range of freshwater aquaculture producers such as rainbow trout, ornamental fish, crocodiles and marron. In **Chapter 7** a synthesis is provided and the contribution of the dissertation to the development of a sustainable aquaculture sector is restated. Recommendations are also made to farmers and policy makers as well as listing areas to be considered for future research.

1.5 Structure of thesis

Hypotheses are not tested for in heuristic research such as this, it is considered not to be necessary. This type of research employed a "discovery approach". Although the research does not use a formal hypothesis, focus and structure are maintained. Therefore, after reviewing the relevant literature and consulting the aquaculture sector, clear research questions were formulated. The structure of the thesis follows the conventional outline of a scientific publication. It comprises of seven chapters of which four are research chapters.

1.6 Research questions

The following research questions were posed:

a. *What were the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?*

  Small water bodies are dynamic structures with erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish and land-based crops.

b. *What were the effects of fish farming on parameters most likely to be influenced by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most* *likely not to be affected by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness).*

It is difficult to partition the influence of aquaculture on irrigation reservoirs which are subject to multiple influences. Therefore we grouped the water quality parameters into groups most likely or not to be influenced.

c. *To what extent does surface and bottom water of the reservoir differ?*

Reservoirs can undergo stratification and form distinctive layers which separate surface and bottom waters. The bottom of reservoirs is also characterised by bio-accumulation of organic material.

d. *What was the nature of phytoplankton occurrence and diversity in irrigation dams?*

Phytoplankton blooms are linked to mesophylic water conditions namely enough nutrients with favourable temperature and oxygen. Harmful algae, such as blue-green algae, can lead to off-taste in commercial fish species, whilst algae not harmful to fish can influence oxygen levels and can lead to fluctuating concentrations associated with producing (photosynthesis) and using (respiration, decomposition).

e. *What is the influence of historical commercial agriculture on farm dam dynamics?*

Most of the farm dams in the Western Cape province have a history of fertilization and pesticide application on the surrounding land. This phenomenon was considered in the description of the water body’s water ecology dynamics.

f. *Can the negative and postitive impacts of aquaculture on irrigation dams and water use be identified?*

Aquaculture in irrigation reservoirs can have a negative as well as positive impact on the water quality and terrestrial land-use. A balanced approach was followed to describe the health and trophic status of the ecosystem.

g. *What is the relationship between fish production data and water quality parameters?*

Optimal fish production is an economic objective of successful aquaculture. It was assessed to what extent prevailing water quality influences fish production and *vice versa*.

h. *What are the land-use changes which could occur in catchments where there is fish farming and what interactions could be described among the changes?*

Aquaculture is one of a myriad of activities within a catchment ecosystem; *inter alia*, commercial and subsistence agriculture, light industry, housing developments, recreation, etc. Aquaculture needs to be described within this context of multiple-use resources.

i. *Does freshwater aquaculture add value to livelihood strategies of rural and peri-urban farming communities?*

It is important to assess the socio-economic contribution of aquaculture in the context of conservation and management of our natural resources. The challenge is to achieve a balance between conservation and development and therefore aquaculture practices should contribute to sustainable use of resources.

j. Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?

Introducing mitigating measures to reduce organic pollution, could improve water ecology. However, it should be possible for farmers to make these measures work.

k. Can eutrophied water bodies be used for plant production?

It is possible to produce vegetables and fruit crops successfully using hydroponic systems in enclosures. Nutrient rich water bodies can be considered as hydroponic systems and therefore it is required to assess the viability of plant production on these large open water systems.

l. What are the challenges associated with technology and knowledge transfers?

In order to practice good management, both fish and land-based crop farmers need to understand the functioning of aquaculture systems in larger open water irrigation reservoirs.

m. What is the public's understanding of aquaculture?

It is necessary to improve the broader public's understanding of aquaculture in order to make them aware of the potential for sector development and associated environmental impact.

n. What are the key issues of consideration by regulators and decision makers?

The government provides the implementation and policing of legislation and policy. Their decisions are based on information forthcoming from applied research.

1.7 Concluding remarks

Key issues to be addressed by the study are sustainability of aquaculture in irrigation dams and the beneficiation for farming communities in terms of socio-economic development. The study is supported by previous research on related aspects, as well as reviews and consultation with persons in the aquaculture sector. The consultation provided a research agenda and assisted in the formulation of research questions to serve as benchmarks throughout the investigation. The envisaged output is to provide additional knowledge complementing our understanding and interpretation of the application and development of aquaculture in irrigation reservoirs in the WCP of South Africa.

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CHAPTER 2 A review of aquaculture practices in multi-used irrigation reservoirs

2.1 Preface

Aquaculture in irrigation reservoirs adds value to stored water in farm dams and enhances productivity through multiple usage (Pullin & Shehadeh, 1980; Behera et al., 2012). Generally land-based pond culture of fish is not an option for many emerging farmers due to lack of access and associated cost of land. Therefore, the availability of land suitable for aquaculture, together with prevailing macro- and micro climate, political stability, government policy, cultural fish consumption patterns and fish market integration affect a country's aquaculture growth and development (Remane, 1997; Boyd et al., 2012). In this regard, the use of existing irrigation structures for fish culture has much potential (Allison et al., 2007). Since aquaculture does not consume water, it will not influence the quantity of the water reserved for irrigation. Many studies around the world have successfully demonstrated the potential of integrating fish production within irrigation systems (Ingram *et al.* 2000, Gooley & Gavine 2003; Pant et al., 2012). At present, with global emphasis on sustainable development, particularly in the agricultural sector, more and more effort is being put into optimising resource use rather than exploiting new ones (Boyd et al., 2008). Agriculture is the largest consumer of water in the world (Behera et al., 2012; Gössling et al., 2012). In South Africa the irrigation of land-based crops and afforestation require approximately 60% of available water (Oberholster & Ashton, 2008). Already numerous small dams, both private and public, have been constructed to store water from catchment areas for irrigation. Thus it seems logical that integrating aquaculture within existing systems can only help to increase overall productivity. Aquaculture is considered relatively new compared to agricultural farming practice and exhibit a wide range of potential development (Edwards, 2009). Whilst it is generally accepted that there is great potential for multiple uses of water storage systems, work needs to be done to enhance the awareness around aquaculture and to build the required capacity to drive the research and development agenda. This approach will enhance the knowledge on the socio-ecological interaction of aquaculture and historical established agriculture.

2.2 General considerations

Over the past decade numerous studies have been conducted on the impact of freshwater aquaculture on the water quality of irrigation dams in South Africa (Du Plessis, 2007; Maleri, 2008; Maleri et al., 2008, Salie et al., 2008; Maleri 2011; Salie et al., 2013). These authors identified the research gaps and presented a new set of instructions and research agendas. They proposed continued assessment of the impact of aquaculture on the water quality of irrigation reservoirs. It was further proposed by these authors to conduct the study over a longer time series and to commission research sites over a diverse geographical spread. Furthermore, it was proposed that mitigation to reduce organic and inorganic pollution to the reservoirs should be evaluated. The literature overview summarized previous work and elaborated on the understanding and general concerns of the public related to the impact of aquaculture on the environment. It underlined the fact that there could be negative as well as positive impacts and placed emphasis on the contribution commercial agriculture has to the nutrient budget of the water body. Notwithstanding that pollution via fish feed and faeces occurs, fish farming systems can also contribute to an increase in the value of water in the system in cases where it is used as a nutrient-rich source for crop production. Behera et al. (2012) reported that besides the plant and animal species turnover in diversity and number associated with the dynamics of the recycling of fish farm effluent and waste within the system, fish farming can also contribute to the improvement of the surrounding environment and towards the preservation of the ecological functioning of wetlands. This interaction is important for wetlands and marshy areas provide mechanical and biological filtering of perennial streams and tributaries.

Milne (2012) devised a nutrient budget for a freshwater reservoir with rainbow trout cage culture and applied a mass-balance approach for the relative contributions of total phosphorous loading from various sources into the receiving waters. The author further described that non-point sources contributed 40 %, whilst the fish farm contributed 33 %. The rest of contributors were made up of groundwater (11 %), dwellings (8 %), phosphorous loading from the hypoxic hypolimnion within the system (7 %), precipitation (3%) and leaf litter (0.3 %). For reservoirs without fish production, the main input of phosphorous (87.9 %) is via inflowing water sources and this accentuates the importance of activities influencing water quality in the pre-fish farm zone (Maleri, 2011). Therefore, the fact remains that as the intensity of aquaculture production increases, so will the phosphorous loading and the potential negative impact on the environment (Kumar & Cripps, 2012). The impact on the water resource can be absorbed when the disturbances are within the upper and lower limits for specific parameters and the reservoir can recover to its former ecological state before the disturbance occurred. The time it takes to recover will depend on the resilience of these ecological systems and the magnitude of the disturbance as well as the nature of recovering to its previous functioning (Walker et al., 2004). Open water bodies have buffering capacities to withstand acute and short term disturbances such as pollution. It is only when such disturbances continue and breach the ecological threshold that the negative impact becomes difficult to be turn around.

2.3 World water resources: extent and use

Freshwater storage systems e.g. lakes, reservoirs, canals and rivers are among the most extensively altered ecosystems on earth (Carpenter et al., 2011). Availability and pollution of freshwater water supplies will be the dominant issues for the global society in the 21st century. With increasing population and predicted climate change scenarios, the demand for water will continue to increase for agriculture (irrigation), and other economic uses to meet future food and energy needs of people around the earth (Kanwar, 2010). Although water is of global primary importance, it remains an increasingly scarce renewable resource in most of the developing world and is one of the biggest constraints to social and economic prosperity in these countries (Herath, 2012).

Approximately 97 % of the earth's water resources are in the oceans and are saline. Only 2.5 % is fresh water, and of that only a small fraction is readily available for use under the prevailing social, ecological, economic and technological conditions (Parish et al., 2012). This fraction, depending on how it is managed, is a potential renewable resource and can supply the demand. It comprises streams, rivers, rainfall and replenished ground water. Annually about 110 000 km^3 of precipitation falls on land and of this, about 70 000 km^3 of water is evaporated (30–50 %) or transpired (50–70 %) by plants from the land surface. The moisture left, roughly 40 000 km^3 runs to the sea. A large portion of subsistence and commercial agriculture is rain-fed, where crops are provided with water harvested directly from precipitation. The increase in agricultural productivity required to support food security needs and the resultant increase in demand for reliable supplies of water will similarly have to be satisfied. Irrigation and water management were identified by the Brandt Report (Independent Commission on International Development Issues 1980) as the biggest single category of investment required in developing countries (Tilbury, 1995). In terms of agricultural improvement about 50–60 % of the increase in agricultural output over the last two decades in developing countries has come from new or rehabilitated irrigated land (Muir & Roberts, 1994). With increased water reticulating systems, it is envisaged that an accompanying water storage network will be developed. This can provide huge potential for integrating aquaculture into these water networks.

2.4 Global aquaculture: growth and challenges

There is a broad consensus that world capture fisheries are under pressure due to dwindling stocks and over-exploitation (FAO, 2012). Global agriculture production for most animal and plant products is expected to present a relatively low growth pattern of 1.5 % for the next decade and there is concern for the threat it poses to world food security for the future (OECD/FAO, 2013). Aquaculture has sustained a global growth of about 8.8 % per annum and is expected to increasingly fill the shortfall in seafood products resulting from static or declining capture fisheries and population increase (FAO, 2012). About 30 % of fish stocks are overexploited and producing lower yields than their biological and ecological potential. The World Summit on Sustainable Development in 2002 emphasized the need that all overexploited stocks be restored to the level that can produce maximum sustainable yield by 2015, a target that seems unlikely to be met (WSSD, 2002). Therefore, a critical case can be made for aquaculture to fill the gap between demand and supply for seafood products. In the last three decades (1980–2010), world food fish production of aquaculture has grown at an average annual rate of 8.8 %. About 600 aquatic species are produced in 190 countries in different farming systems with their own input intensities and levels of technological sophistication (FAO, 2012). In 2010 it has been estimated that fisheries and aquaculture provided livelihoods and income for an estimated 55 million people active in primarily fish production. The total world fisheries stands at 154 mt of which total capture fisheries contribute 90.4 mt (59 %) and total aquaculture 63.6 mt (41 %). Fish and fishery products represent a very valuable source of protein and essential micronutrients for balanced nutrition and good health. In 2009, fish accounted for 16.6 % of the world population’s intake of animal protein and 6.5 % of all protein consumed (FAO, 2012). Freshwater fishes dominate global aquaculture production (56.4 %) with the majority of production coming from South-east Asia region (FAO, 2012).

In many countries it is foreseen that the aquaculture industry can contribute significantly to growth and development. For it to happen, it has to be within a sustainable environment, be socially acceptable and economically viable. Therefore it is proposed that future growth and development of aquaculture will be driven under a different socio-economic perspective for the approaching millennium (De Silva, 2012). For aquaculture to develop into an environmentally and socially responsible food production sector, it is recommended that more ecological sustainable practices be implemented e.g. integrated farming systems and efficient treatment and recycling of farm effluent. It is also postulated that the use of closed systems with low discharge be encouraged e.g. recirculating aquaculture systems and fish production should be directed to decrease their reliance on wild fisheries for fishmeal products. It is proposed that fishmeal in aquafeeds should be complemented or replaced with plant-based feed ingredients and overall better management practices for sustainable aquaculture on farms implemented (White et al., 2004). “The global challenge is to build our human resources capacity amidst pressure for all development to be environmentally and socially acceptable, irrespective of the economic status of nations" (De Silva et al., 2012).

2.5 Integrated fish farming in irrigation systems

Increased food production requires more water. Water is a finite resource and its availability is limited by natural availability through the water cycle. "As water becomes an increasingly scarce commodity, water productivity has to increase through diversified farming systems" (Behera et al., 2012). Existing methods and networks for water storage and distribution are only partially used for fish production (Ingram et al., 2000). Therefore the rational to optimise usage is that integrating aquaculture into irrigation systems in relation to the micro climate, location in the catchment area, reservoir size and extraction rates is considered to be a viable option to increase the value and usage of water bodies (Pullin & Shehadeh, 1980; Barrow, 1987; Gál et al., 2011). Irrigation is a consumptive user of water which means that it may not be feasible to combine it with aquaculture if the water requirements for irrigation are too high. Fluctuating water levels in reservoirs pose a constraint to aquaculture development for minimum required levels to support fish farming cannot be maintained. However, the Mediterranean climate of the WCP ensures that winter rainfall fills reservoirs and supply sufficient water for summer irrigation. Therefore most reservoirs in this region maintain water levels that can support fish farming throughout the year (Salie et al, 2008). Irrigation projects are usually planned primarily to benefit agriculture by improved water availability. Thus, there is a premium on primary water use for land-based crop irrigation (Gössling et al., 2012). Similarly, aquaculture can affect the water quality within the system. If aquaculture operations alter the water quality of these reservoirs to such an extent that they impact detrimentally on the irrigation systems, then integration may also not be feasible due to excessive algae growth resulting in clogging of emitters and filters. Therefore the fitness-for-use of the water for both aquacultural and agricultural activities is to be maintained to sustain optimal functioning of such an integrated multi-resource utilization system. Irrigated farm land will always have a premium on water access and use in most countries and therefore management has to adopt policy which facilitates and enhances cooperation between the different users of the resource.

The risk of clogging of irrigation equipment (sprinklers and drip-emitters) is a general problem irrespective whether aquaculture is practiced or not in the water body (Du Plessis, 2007; Wenquan et al., 2012). The feeding of fish in floating net cages could lead to higher nitrogen, phosphorus and organic matter content in the water. As a result, algae growth could increase due to availability of micro- and macro nutrients. In such cases eutrophication can persist to detrimental effect for both high value fish and land-based crop farmers. On the contrary, eutrophic waters have a high potential for low cost aquaculture where omnivorous and herbivorous species such as tilapia, catfish and carp can be cultured extensively and food is only supplied via the natural productivity (Little & Muir, 1987; Shoko et al., 2012). In semi-arid and arid areas where water is a scarce and valuable commodity, competition amongst agricultural, domestic and industrial users may necessitate and stimulate integration of water use. This can be seen in some countries where more than 20 % of the total fish production coverage has been adapted to accommodate water storage/irrigation systems. Countries such as Israel and Australia are on the leading edge of developing multiple water-use systems (Gooley & Gavine, 2003). These are water-scare countries and are continuously required to develop strategies to optimise usage of existing water resources. Therefore, expansion and intensification of agriculture requires increased availability of water. Thus, increased irrigation will result in an increase of water storage in reservoirs. There is huge potential to integrate aquaculture as a non-consumptive water user with agriculture use and storage.

2.6 Interaction of aquaculture with irrigation reservoir dynamics

Although large amounts of water are often stored in reservoirs, its use may be problematic for multiple uses. Primarily these semi-artificial ecosystems are planned and constructed for purposes of water storage for public and private use, for recreational activities, tourism, fisheries and irrigation (Tundisi & Matsumura-Tundisi, 2003) and aquaculture is deemed a potential secondary activity. An increase in the development of larger freshwater bodies resulted in fewer aquaculture activities and is more directed towards the resource management of wild-caught fish species and fisheries (Pillay & Dill, 1979). Fish yields extensively based on natural productivity of water storage bodies are approximately twenty times lower compared to intensive managed fish production systems. Higher yields are possible due to efficient management characterised by optimal stocking of fish, using formulated diets to enhance growth, controlling occurrence of predation and regular harvesting of fish. “Cage culture may provide a rational means of exploiting large public waters for the benefit of land-poor communities and the techniques can make intensive management and high yields possible” (Ayyappan, 2012). In rural and peri-urban areas where new reservoirs were built, there are often associated needs to provide alternative livelihood and income for relocated and displaced communities. Net cage farming of fish on these open wate bodies, as with land-based pond culture, can be performed with fish feeding extensively (only natural productivity of water body), semi-intensively (partial complement of natural or artificial feed) and intensively (fish are only fed complete artificial diets). The use of formulated diets and optimal stocking densities is becoming more widespread for omnivorous species such as tilapia in warmer waters and carnivorous salmonids in colder waters. Cultured apex carnivorous salmonid species such as rainbow trout have traditionally been fed diets with high inclusions of fish oil and fish meal. The demand for fishmeal inclusion in diets for animal production is unsustainable for raw materials are expensive and add pressure to wild fish stocks. There is a huge effort in the aquaculture industry around replacing fish meal and fish oil with alternative raw materials from plant derivatives (Gatlin et al., 2007). Therefore cage culture of fish in eutrophic waters with species feeding lower in the food chain (i.e. tilapia, carp and catfish) have the potential for low cost fish production and an increased usage of the water resource (Diana et al., 2007). The success of cage culture in freshwater bodies is based on the efficiency and quantity of fish yields and if yields are low, the cost of cage construction may limit further exploitation and development of the farming concept. There also exist other potential conflict scenarios between cage culture operators and other water uses in the catchment and the following discussion elaborates on the dynamics of these interactions.

2.6.1 Water ecology

a. Mixing patterns and influent quality

Retention time of water in reservoirs is of fundamental importance in determining mixing. Most “small” reservoirs have a short retention time while larger ones have longer retention time with an anoxic hypolimnion irrespective of its trophic status (Tendaupenyu, 2012). The retention time should be of appropriate duration for complete horizontal mixing. Furthermore, thermal stratification can also result in vertical variation in quality although it rarely occurs in shallow reservoirs (< 10 m) but in deep reservoirs (> 30 m) it is usually present (Van Dijk & Van Vuuren, 2012). In intermediate depths the occurrence of stratification depends upon the climatic and topographical conditions. Where stratification occurs, the reservoir can be described as a two-part system with the bottom sediment layer forming the third component. The bottom layer of the reservoir (hypolimnion) is considered the unproductive layer due to low DO concentrations and high concentrations of hydrogen sulphide, carbon dioxide and ammonia.

b. Physical and chemical processes during storage

The retention period of water in irrigation reservoirs is usually spread over months and provides sufficient time for water quality to change through physical and chemical processes. “The main physical process affecting water quality in reservoirs is sedimentation, although other processes like adsorption may be important for some pollutants” (Jacobson & Jacobson, 2012). Sedimentation creates nutrient sinks which could lead to water quality deterioration once bottom waters are mixed with surface waters in windy, turbulent conditions. Fluctuating weather conditions can also affect the physico-chemical constituents of the water. Subsequently, the occurrence of eutrophication and the rate and extent of sedimentation is determined (Hughes et al., 2012). Monitoring and evaluation of changes in trophic status of reservoirs become important to enable prediction of cyclic events affecting the ecology of reservoirs and the envisaged future usage.

c. Biological changes

The biological changes within a water system are often controlled by external natural and human impacts, which can be positive or negative. “Most of the important changes in water quality in reservoirs occur as a result of the activities of micro-organisms” (Van Ginkel, 2012). When conditions are favourable for micro-organism activity the associated nutrient uptake and recycling determine the characteristic and physical changes of the water resource (Ojo et al., 2012). Thus, there is a continued requirement to provide management and treatment options for eutrophication in order to increase the benefit of existing water resources and decrease the cost associated with multiple users. Recent studies, including (Maleri, 2011), reported on the effects of rainbow trout cage culture on Western Cape irrigation reservoirs and found that already prevalent eutrophication levels can be accelerated with fish production. However, her study also emphasised that there were exceptions where fish farming is possible without negative effects on the environment. Therefore it is important that these sites are used to demonstrate successful integration of aquaculture into existing water storage systems.

2.6.2 Land-use patterns in the catchment

There are different land-users spread along the reaches of the catchment area. Upper reaches of this ecosystem are usually underutilised due to its inaccessibility and is therefore considered to be pristine in terms of natural indigenous vegetation cover. The middle and lower reaches are characterised by anthropogenic activities for forestry, agriculture, housing developments and light industries (Meek et al., 2010). Thus, many authors have concluded that input of nitrogen and phosphorus from both point and non-point sources causes deterioration of the water quality of such freshwater ecosystems (Kronvang et al., 2005, Turpie et al., 2010; Passeport et al., 2012; Smith et al., 2012). "Evaluation of relations between land-use in reservoir and riparian zones proved to be difficult because reservoir water quality presumably is an integral part of a wide range of local catchment and tributary processes. Thus, reservoir water quality is linked to surface activity in the whole catchment and is directly associated with the proportion of agricultural land-use in the entire catchment" (Nielsen et al., 2012). Efficient water resources management is considered to be difficult for potential conflicts in water use may be related to the spatial and temporal variability of the climate and availability of the resource. The demand for access to water may obscure the rationale for sustainable use. This is more problematic where primary livelihoods are threatened due to limited or no access for communities to water resources.

The water recycling system has well-defined sub-components, *inter alia*, the catchment area, the reservoir or storage structure and the irrigated demand from agriculture. The system can be replicated to model pollutant loading at a variety of spatial scales (De Smedt, 1989; De Groeve, 2003; Gassman et al., 2007). It provides a useful tool for integrated catchment management. However, reservoirs in the WCP are small-scale and do not justify detailed, intensive and very expensive hydrological investigations. It is within this context of limited hydrological research on reservoirs that aquaculture needs to be evaluated in term of its role and function in a catchment with regard to physical land occupation, quantities of water stored and the contribution to the nutrient budget. Maleri (2011) and Milne (2012) both described the phosphorous contribution of salmonid aquaculture through a mass-balanced approached and found that it contributed on average 52 % and 32 % respectively. Furthermore Anh et al. (2010) described that one ton of frozen *Pangasius* fillets releases 27 kg of phosphorous of which 60-90 % was from the fish farm and 3-27 % from processing. Bian et al. (2012) found that for every one kg of grass carp produced, there will be 0.33 kg of phosphorous released to the water. "Hence, a holistic approach for catchment management should be considered when evaluating nutrient loadings to reservoirs, and future policies should ideally target mitigating measures that reduce the input to the catchment to successfully improve reservoir water quality" (Nielsen et al., 2012).

2.6.3 Mitigation to reduce pollution

It is generally accepted that farm effluent from aquaculture contributes to pollution of water resources (Anh et al., 2010; Carpenter et al., 2011; Gu et al., 2011; Allison, 2012). Although fish farming effluent can contain a number of organic and inorganic pollutants from feed and faeces, the two key nutrients that are essential for life in freshwater ecosystems are P and N compounds (Battarbee et al., 2012). However, the increase of N and P concentrations could fuel eutrophication in reservoir ecosystems. Hyper-eutrophication could reduce the reservoir's biodiversity in plant and animal life and the ecosystem's resilience to future deterioration of water quality. Such deterioration can be ascribed to effluents from aquaculture, additional anthropogenic stress as well as the potential influence of climate change (Grizzetti et al, 2012; Van Ginkel, 2012). "The role of climate change is accentuated when a short term decrease in nutrient loads could be the result of a dry period, while a wet period could mask some improvements in nutrient reduction" (Boyd et al., 2012).

Mitigation to reduce P pollution were more successful than those applied to reduce N and policies aimed at managing pollution from point sources were more effective than non-point sources (Battarbee et al., 2012). Since feed is the single most important source of waste (P & N) in net cage aquaculture, mitigation should be directed firstly at reducing loading through improved feed formulation and feeding management and secondly through extracting and removal of suspended and dissolved substances originating from farming culture activities such as faeces and wasted feeds. “A controlled waste reduction strategy is necessary to maintain sustainable aquaculture growth into the future” (Amirkolaie, 2011). Much work has been successful on improving the quality of farm-made and commercial diets. Other methods and filtering systems have been explored to collect and remove accumulated feed, dead fish and faeces still in solid form. These measures included net cage liners (tarps) and semi intensive floating tank systems where approximately 80 % of waste within the system can be effectively removed (McRobert & Partridge, 2005). Other mitigation measures include polyculture farming systems where two or more animals feeding at different trophic levels were employed in symbiosis i.e. crustaceans with salmonids (Klinger & Naylor, 2012). In this instance the salmonids are the primary product and feed on supplied artificial diets and the crustaceans are the secondary product feeding on fish waste and uneaten feed. The crustaceans limit the bio-accumulation of organic matter and help reducing pollution in the water column. Aquaponics is another farming system where plants are grown in conjunction with fish in a water recirculating unit. The fish fertilizes the water and provide vital macro- and micro nutrients for plant growth, whilst the plants functioned as biofilters maintaining good water quality for fish production (Rakocy & Hargreaves, 1993). Mitigation should be focused on reducing the net nutrient loading irrespective whether the origin of the source. This strategy can contribute to achieving a well-balanced ecological system for any reduction in nutrients would limit microbial activity leading to eutrophication.

2.6.4 Socio-economic contribution

Fisheries and aquaculture provide a crucial investment to the world’s well-being and prosperity and contribute to livelihoods of millions of men and women (Ross et al., 2008; Edwards, 2009; Murshed-E-Jahan & Pemsl, 2011; Ahmed et al., 2012; Daou, 2012; FAO, 2012). The contribution could be direct through improvement in household income, subsistence food supply and skills enhancement. Indirect benefits could include providing an information hub for other emerging farmers, elevation of status in the community through greater wealth and knowledge creation and promoting sector diversification through new products and technology. The average food basket of households can also improve through the availability of various forms of protein sources. Readily available and affordable fish and fish products can contribute to expanding the diversity of household food commodities.

The challenge is to find a balance between the socio-economic requirements of a community and to sustain the ecological integrity of the farmed area. It is incumbent that knowledge transfer on best practices and guidance should be appropriately adapted to a variety of environmental, geographic, socio-economic and political settings. “Aquaculture development should be socially responsible and equitable to enhance the natural resource base and livelihoods” (Bunting, 2013). To realise the full potential of aquaculture, an enabling environment should be fostered to encourage investor and consumer confidence (DAFF, 2012; Porter et al., 2012). Furthermore, sustainability cannot be divorced from the social aspects and therefore the linkage of operational efficiency with environmental performance can enhance the optimising of the allocation of resources while minimizing impacts (Fitwi et al., 2012). Björklund et al. (2012) postulate an ecosystem-based approach to agriculture practices (inclusive of aquaculture) whereby food production and conservation are combined as a potential viable and sustainable way of feeding the world in the long term. An ecosystem-based approach to aquaculture management is a strategy for its integration within the wider ecosystem. An all-inclusive-system will take cognizance of the fact that the process is transparent and participatory in such a way that it promotes sustainable development, equity, and resilience of ecosystems (Cranford et al., 2012; FAO/NACA, 2012; Milne, 2012; Rosa et al., 2102). Ultimately research and development of aquaculture should encourage an approach whereby farming systems are deployed to reinforce environmental protection policies and regulations.

2.7 Concluding remarks

Water resources are a precondition for the existence of human populations around the world, and one of the most important raw materials for our economic activity and welfare. Water is increasingly being seen as a limited resource and greater attention is being focused on priorities for its allocation and management. Increasing drought affecting the African continent, the problems of flood control and general water quality in South-east Asia, and the impacts of development on coastal and freshwater resources in the Amazon basin in Latin America all point to the particular and vital importance of water resource management in developing countries. The growth of the South African population and the pressing demand from a myriad of users intensify the challenge associated with proving sufficient water supply for rural, urban and industrial demands, as well as agricultural needs to meet food production requirements.

Globally available water resources are increasingly being threatened by pollution from point and non-point sources which could reduce the quality and usage. With increased demand on existing water resources, the usage needs to be optimised with controlled and efficient management to limit eutrophication and further deterioration of the water quality. Integrating aquaculture into irrigation reservoirs should be promoted as a non-irrigation benefit. Aquaculture can contribute to the overall value of water through diversifying the existing utilisation patterns. Farming systems have been evaluated to incorporate multiple water use for irrigation reservoirs and include aquaculture into the wider context of planning, development and management of water bodies. Particular attention has been focused upon fish production from engineered water systems for storage and opportunities to extend the potential for these forms of integration.

Most forms of waste are regarded as a resource out of place and can have deteriorating effects on the terrestrial and water ecology when mismanaged. Aquaculture can improve the efficiency of water use and even enhance its value by providing nutrients in the farm effluent for land- and water-based plant production. Nutrient-rich waters (N & P) can also be conveniently used for irrigation of land-based crop production and reduce the reliance on fertilisers to maintain arable land (Hanjra et al., 2012). It can further enhance wetland and riparian regeneration and ecological functioning, thus providing a habitat for plant and animal recruitment (Idris et al., 2012).

In order to consider the benefit gained from South Africa's existing water resources, it is important that the relevant ecosystems are thoroughly investigated and consulted to present an environmental sustainable, socially acceptable and commercially viable partnership. Not only will this prevent conflict between potential water users, but it will also allow insight into where and in which manner diversified farming systems would expand in the future. Aquaculture is a user and not a consumer of water and therefore should not infringe on water requirements for agriculture and other users. However, there might be potential conflict in the demand for water space and access pathways in a catchment.

Aquaculture is considered to be the blue revolution for it is envisaged that most of the future's demand for food fish will come from fish farming initiatives. The potential socio-economic benefits that aquaculture can bring to rural and peri-urban communities, accentuates the motivation to exploit aquaculture in the water storage networks of South Africa.

Therefore, to enhance aquaculture development there is a need to understand the driving forces of its uptake and issues that discourage intiatives. Intervention are required to understand the complexities imbedded in these processes and systems in order to determine the lessons learned from aquaculture initiatives and to evaluate opportunities and challenges presented to the desire to grow, develop and extend aquaculture practices.

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CHAPTER 3: Description and analysis of water quality and production parameters to quantify environmental impact

Abstract

Seasonal fish farming of rainbow trout (*Oncorhynchus mykiss*) in irrigaton reservoirs in the Western Cape province of South Africa has proven to be successful. High value trout were produced for the fresh and processing market. Typically, most of these fish farming dams function as multiple-use systems with irrigation as the primary use and aquaculture secondary. Other uses included household drinking water and areas for recreational use. Eutrophication of farm dams can occur via a number of external sources including agricultural runoff, household and industrial effluent and plant and leaf litter. Aquaculture can also contribute to the nutrient budget of such water bodies. The water quality in reservoirs was monitored over a period of four years to quantify the impact of aquaculture. Samples were taken from surface and bottom layers. Water quality variables were described for the surface and bottom waters, for the different site locations and whether fish farming or no fish farming was present. An ANOVA was conducted to determine the variance among groups. The production data of the fish farms were also compared with selected water quality parameters to determine the influence of water quality on production output of fish farms. The phytoplankton groups were also described. Results indicated that there were no statistical difference between fish farming and non-fish farming dams for dissolved oxygen, total ammonia nitrogen, nitrate-nitrogen, iron, boron, copper and zinc. The phytoplankton analysis indicated that the Chlorophyta group had the most occurrences (n = 371), followed by Bacillariophyta (130) and Cyanophyta (66). There was a statistical significance between occurrence and season for phytoplankton. The results of the analysis of the production data indicated that source of fingerling for stocking and the FCR were the two aspects affecting the final weigh of fish harvested. Although most of the water quality parameters indicated an increase in concentration where aquaculture was practiced, the increases were of such quality that the ecological integrity of the water body was not compromised, except where aquaculture was practiced in water bodies already eutrophied prior to aquaculture. All the farms were also seasonal, thus each year with the winter rains, dams would overflow leading to flushing and water replacement. This phenomenon changes the prevailing water quality regime. The study revealed that quantifying the agents of water pollution is complex and irregular in relation to seasonal fluctuations. Therefore it was proposed to encourage both land-based crop farmers and fish farmers to facilitate management that reduced any potential pollution to the water body.

3.1 Introduction

Farm dams have proven to be viable water bodies for selective fish production. However, both extensive and intensive fish farming can contribute to eutrophication of these dams. The main wastes derived from fish production are fish faeces and uneaten feed and is rich in P and N which have the potential to alter the trophic status of the water (Temporetti & Pedrozo, 2000; Daou, 2012). In cases where eutrophication is occurring the value of water is compromised and the benefit to household and commercial use will continue to decrease (Oberholster & Ashton, 2008). Thus, the challenge to fish farmers is to manage their water quality within the South African Water Quality Guidelines described in DWAF (1996) in order to maintain a healthy environment for fish production and ensure that the water quality for crop irrigation is sufficient.

Increasing pressure on water utilization has necessitated rethinking and proposing alternative approaches to the management of South Africa's water resources. The custodians of our water resources are continually faced with the challenging task of forward planning to meet the water needs of the country and non-conventional methods are being considered to address water resource and demand management (DEAT, 1999; Grobicki & Cohen, 1999). The use of irrigation water bodies for aquaculture is becoming increasingly common worldwide and provides a system to alleviate the pressure on the demand for primary water usage for food production. South Africa has a network of more than 5000 registered dams of which a large number are considered to be suitable for aquaculture (Salie et al., 1998).

An ecological balanced farming system in irrigation dams will provide viable fish production and simultaneously adhere to management guidelines to ensure and sustain acceptable quality of the water resource. Aquaculture-agriculture is a dynamic system with different internal and external factors affecting the ecological balance (Fernando & Halwart, 2000; Ingram et al., 2000). The monitoring and evaluation of the physico-chemical water quality parameters are the first steps leading to the management and conservation of our aquatic resources (Garg et al. 2010). In this chapter the impact of aquaculture on the water quality of irrigation dams is monitored and evaluated.

3.2 Research scope

Earlier studies established a water sampling and monitoring protocol to monitor and evaluate the impact (negative & positive) of aquaculture on the water quality of storage dams. Outcomes from the previous studies highlighted the critical concepts and agents influencing the water quality of these systems, as well as areas of impact. In these studies a limited number of sites were reported on and the need for more research sites over a wider geographical area was identified (Maleri et al., 2008; Maleri 2011). This can extend and validate findings from previous research. More research sites will also allow the identification of patterns and processes in dam systems with different characteristics and associated ecological interaction. The collection of a larger database will furthermore allow the classification criteria of dams for site selection procedures. Therefore the number of research sites in this study was extended to an additional 29 sites. The research site information, including production years, geography, hydrology and land-use of respective farms is shown in Appendix 2.

3.3 Fieldwork setting (study area)

All farm dams monitored and evaluated are situated along catchments located within the Boland and Koue Bokkeveld regions of the WCP. The general location of the sites is indicated on the Google Earth maps. Pictures of some of the sites in each geographical grouping are also included. Figure 3.1 indicates the overall geographical distribution of dams monitored.

The dams were grouped, as follows, according to their geographical distribution:

- Eight in the Overberg region, Grabouw/Caledon area.
- Ten in the Boland region, Stellenbosch/Paarl area.
- Eleven in the Breede River region, Ceres/Worcester area.

These regions are potential nodes for freshwater aquaculture development in South Africa (Maleri et al., 2008).

Figure 3.1. Google Earth™ satellite photograph of the overall geographical distribution of dams monitored during the study.

For each group, two sites were randomly selected and information was collected on water usage, surrounding vegetation and agricultural activity as well the fish farming history. The described sites served as an example of site characteristics for that particular area. Additional comments were also included for each site. The geographical distribution of dams monitored in the Grabouw/Caledon area is indicated in Figure 3.2.

Analysed sites in the Grabouw/Caledon area:

The Nuwejaarsrivier site is one of two projects that were farmed for all four years (2008-2011) of the research period. The dam receives water from a spring source and from runoffs. The surrounding landscape is covered with Fynbos vegetation. The agricultural land has vegetables and fruit trees under irrigation. The dam has a high turnover rate of water (more than twice a year) and there is a continuous flow from the dam. Figure 3.2.a. indicates a relatively small surface area, but due to the high turnover rate, fish has been farmed successfully for the whole research period, except for 2011, when there was a total fish kill. The reason for the mortalities was not fully understood and no conclusive evidence could be provided. It was believed that rising pH could have been a contributing factor.

The Voorhoede site had a relatively short aquaculture history (2008 & 2009). The dam receives runoff water from the surrounding catchment. Water is also pumped from other storage dams on the farm. The vegetation type is Mountain Fynbos with pockets of pine plantation. In Figure 3.2.b. it can be noticed that the farmer is stocking the cages with juvenile trout via a pipeline from the truck to the cage. The water is used for the irrigation of vineyards and fruit trees.

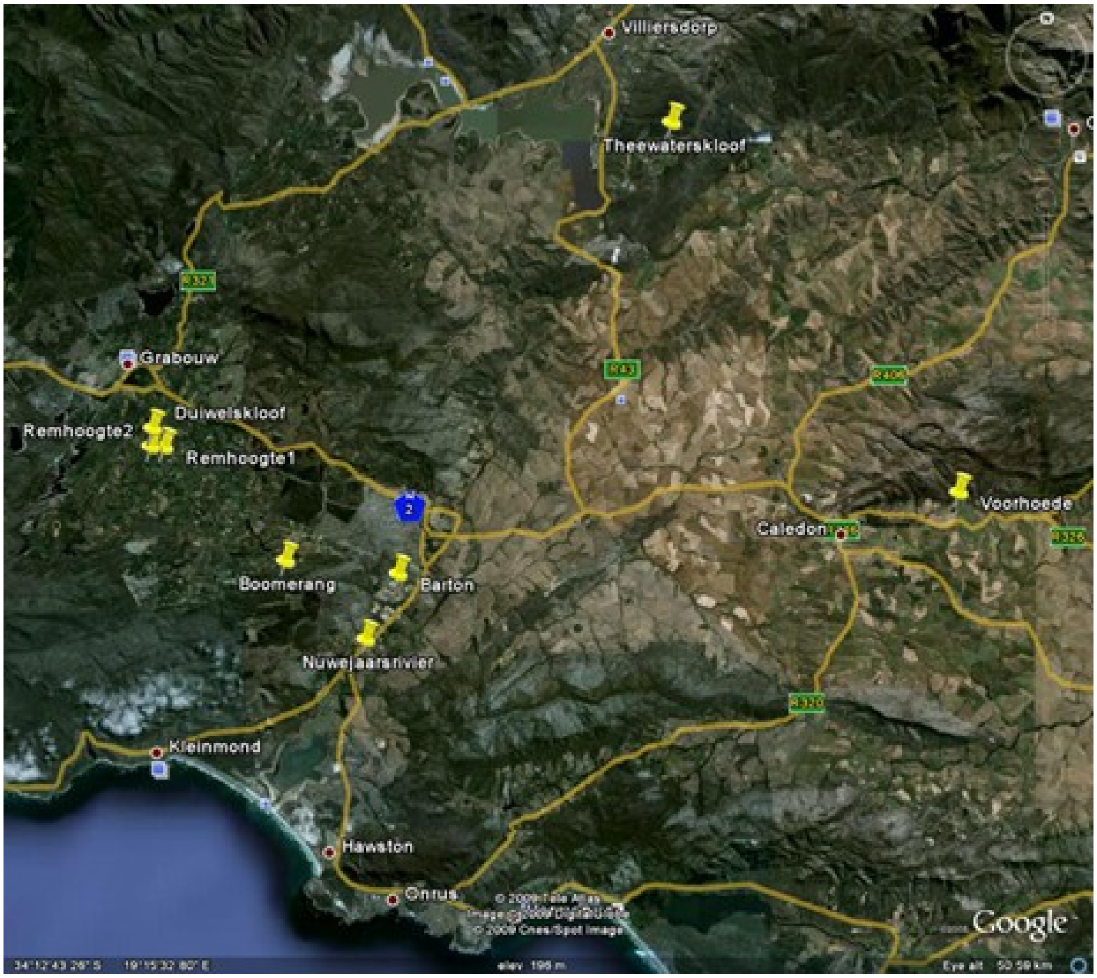

Figure 3.2. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Grabouw/Caledon area.

Figure 3.2.a. Wide-angled picture of the Nuwejaarsrivier experimental site.

Figure 3.2.b. Wide-angled picture of the Voorhoede experimental site.

Analysed sites in the Stellenbosch/Paarl area

The geographical distribution of dams monitored in the Stellenbosch/Franschhoek area is indicated in Figure 3.3. The Nietvoorbij site has the longest aquaculture history of all the dams in the monitoring program. The first fish farming was started in 1996. During the monitoring period it was only farmed during 2008 and 2009. It receives water from runoff as well as pumped water from the Plankenbrug River. The water is used for irrigation of vineyards. Long term monitoring and evaluation indicated that the dam might have reached its threshold in carrying capacity for continued aquaculture based on recent water quality results. Additional enrichment of the dam in future will be caused by wine cellar effluent as well as a large population of Egyptian geese. Figure 3.3.a. indicates the location of the floating cage system anchored in the deepest part of the dam, and the surrounding vineyards under irrigation.

The Mountain Vineyards site is one of the recent aquaculture projects. Fish farming was started in 2009 and the site was farmed during 2010 as well as during the monitoring period. The dam receives water via streams from the Simonsberg catchment and from a pipeline from higher dams. It has a large surface area and the water is used for the irrigation of vineyards and fruit trees such as oranges and pears. Figure 3.3.b. shows the Simonsberg Mountains in the background with the vineyards stretching from the foot of the mountains to the dam. The damwall was covered with well-established Fynbos vegetation.

The research sites for Wijzersdrift and Hexron were not monitored from winter 2009 onwards for the quality of the assessment has been compromised. Both dams were almost pumped dry and the sites were difficult to sample in the muddy conditions. The geographical distribution of the dams monitored in the Paarl/Worcester are shown in Figure 3.4. This area has many dams higher in the catchment and presents good potential for future aquaculture activities.

A start was made with aquaculture at the Goedgeloof site in 2008 and trout farming took place there for three consecutive years. The dam receives water which is pumped from an irrigation scheme as well as runoff from the surrounding landscape. The surrounding agricultural land is covered with vineyards and fruit trees under irrigation. It is a relatively newly constructed dam. Goedgeloof is the best-performing small-scale fish farming project in terms of sustainable management of both fish farming and the surrounding environment. In Figure 3.4.a. it can be seen that the vegetation is still being established on the damwall.

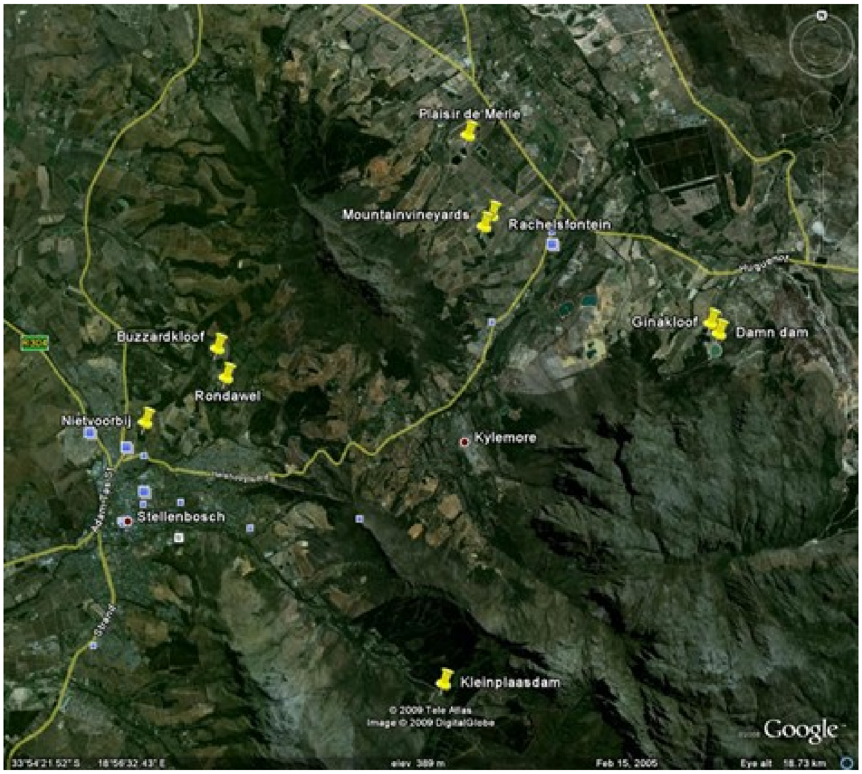

Figure 3.3. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Stellenbosch/Paarl area.

Figure 3.3.a. Wide-angled picture of the Nietvoorbij experimental site.

Figure 3.3.b. Wide-angled picture of the Mountain Vineyards experimental site.

Analysed sites in the Paarl/Worcester Area

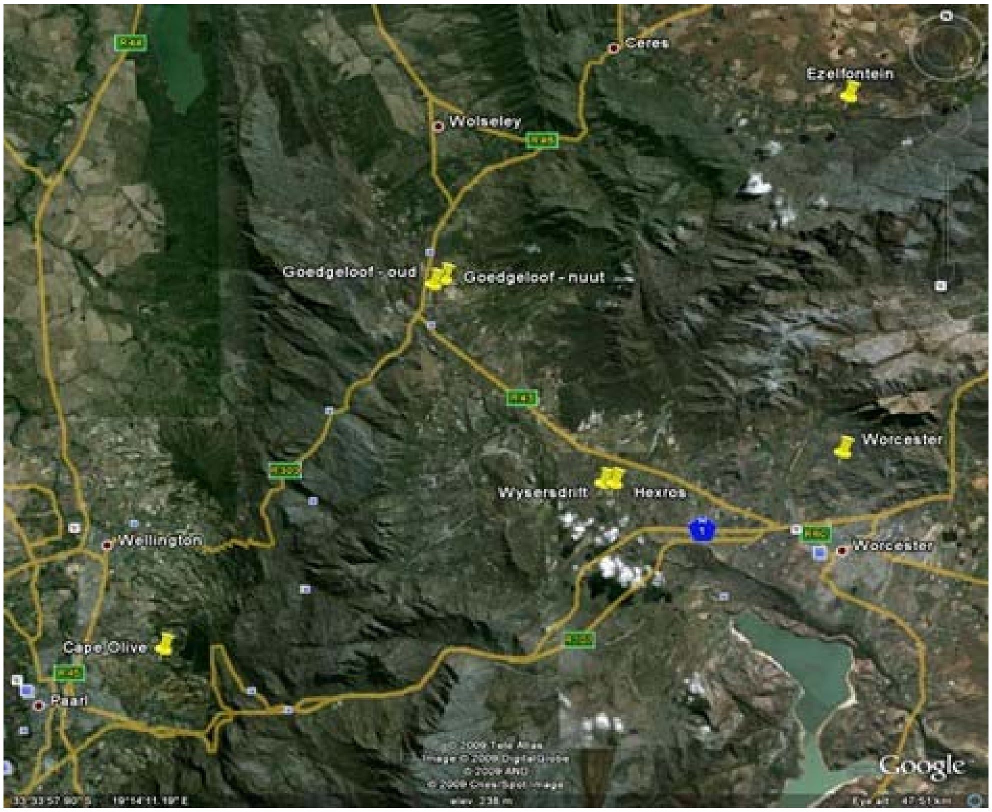

Figure 3.4. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Paarl/Worcester area, with the exception of Wijzersdrift and Hexron which were omitted from winter 2009 onwards.

Figure 3.4.a. Wide-angled picture of the Goedgeloof (new) experimental site.

The Worcester site has an aquaculture history of approximately six years. The project produced trout in 2008 and 2009 during the period the research has been conducted. The area surrounding the dam is characterized by Fynbos and semi-Karoo vegetation. Dam levels are maintained through runoff from winter rains as well as water supply via a pipeline from a drinking water dam located higher up. The dam has been used for more than a century by local fly-fishing clubs for recreational angling. The water is also used for the irrigation of a nearby golf course. In case of uncontrolled veld fires in the Worcester area, water is extracted from this dam to extinguish these fires. Figure 3.4.b. indicates the natural vegetation surrounding the dam and two well-maintained access roads.

Figure 3.4. b. Wide-angled picture of the Worcester experimental site.

Analysed sites in the (Ceres) Koue Bokkeveld Area

The geographical distribution of dams monitored in the Ceres District (Koue Bokkeveld) is indicated in Figure 3.5. The dams Slangboskloof and Helpmekaar were not monitored from winter 2009 onwards due to challenging research logistics. The Koue Bokkeveld area is deemed to be the future focal point for trout production given its favourable water temperatures. The area is characterized by a network of irrigation dams with cooler summer water temperatures which can accommodate year-round production.

The Rocklands site was densely stocked during 2008 and produced marketable trout in the production year of 2009. The dam receives water from three feeder streams from the surrounding catchment. The area is characterized by mountainous outcrops and luscious Fynbos vegetation (Figure 3.5.a). Allegedly the project was terminated due to the blocking of irrigation systems. It is postulated that the fish farming had an impact on the phytoplankton abundance and diversity and it is linked it to a drop in water level depth and the ready availability of nutrients (F. du Plessis, personal communication, 30 August 2007). The water is used for the irrigation of fruit trees.

The Môrester site has a very short history of aquaculture. It only produced trout in 2009. Water is supplied to the dam via runoff from the surrounding mountains. This seems to be the only source of water. The site is remotely located in mountains and is difficult to access during rainy conditions (Figure 3.5b). It is one of a few sites with a constructed weir which can be monitored for overflow volumes. It is noticed that the dam was overflowing during this site visit. The water is used for the irrigation of fruit trees and vegetables, as well as serving as a drinking hole for wild animals. The higher elevated sites provide excellent winter water temperatures for trout farming.

3.3.1 Location of sites

The commissioned sites were located in the WCP of South Africa within a 200 km radius of Stellenbosch University in Stellenbosch. Sites were limited to this area to facilitate visiting farms and collecting water samples in short periods of time. For the purpose of data analysis, the sites were grouped into three regions.

The regions are Grabouw/Caledon, Stellenbosch/Paarl and Ceres/Worcester. The regional distribution of the commissioned research sites is indicated in Table 3.1.

Figure 3.5. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Ceresarea (Koue Bokkeveld), with the exception of Slangboskloof and Helpmekaar which were omitted from winter 2009 onwards.

Figure 3.5.a. Wide-angled picture of the Rocklands experimental site.

Figure 3.5. b. Wide-angled picture of the Môrester experimental site.

Table 3.1. Regional distribution of commissioned research sites.

Grabouw/Caledon	**Stellenbosch/Paarl**	**Ceres/Worcester**
Remhoogte 1	Nietvoorbij	Ezelsfontein
Remhoogte 2	Rondawel	Rocklands
Duiwelskloof	Buzzardkloof	Soetfontein
Boomerang	Jonkershoek Kleinplaas	Boplaas
Theewaterskloof	Rachelsfontein	Morêster
Nuwejaarsrivier	Damn Dam	Weltevrede/Tweefontein
Barton	Ginaskloof	Toeka
Voorhoede	Plaisir de Merle	Westland/Kolk
	Cape Olive	Worcester
	Mountain Vineyards	Goedgeloof (old)
		Goedgeloof (new)

2.3.2 Suitability of sites

Sites were selected as per recommendations stipulated in Maleri et al., (2008). The authors suggested that certain aspects should be considered such as dams should have a minimum size of 8 ha and be exposed to regular wind action to allow longer mixing phases. In cases where no aquaculture was practiced at the sites, the potential for fish farming was also investigated and discussed with farm owners. It was important for the study that sites should be available for the duration of the study and therefore regular communication with farm owners was undertaken to inform them about the progress of the research as well as developments in the aquaculture sector. Although all care was taken, there were instances when the fish farming status changed or sites were not feasible to be continued with sampling. Furthermore, information was obtained on geochemistry and hydrology (e.g. underlying geology, soil erosion, depth, surface area, volume replacement, mixing regimes, etc.), on vegetation (e.g. dominant vegetation type, physiognomy, etc.), and on agricultural activities in the surrounding catchment. This enabled the researchers to identify trends and processes for water ecology in farm dams in relation to the different characteristics of a specific region, and agricultural history.

2.4. Materials and methods

Water samples were collected from 29 sites four times a year over a period of 40 months (June 2008 to August 2011). Sampling was collected in duplicate from the sites in each of the four seasons. All the water bodies were irrigation reservoirs (farm dams). The sizes of the dams were all in the range of 2-12 ha in surface areas. The depths varied from 6 to 18 m. One farm produced fish during all four the years and one farm did not produce at all. On all the other farms production was intermittent. Only one cycle of trout production was completed during one year and projects had a dormant period over summer. The production season is generally from April to November in the WCP (Salie et al., 2008).

All the research sites had a designated sampling point to ensure uniformity of sampling areas. The point was marked with a buoy. Samples were transported from these buoys with a canoe. Samples were also taken in more or less the same time period. Sampling was scheduled to coincide with the different seasons i.e. summer, winter, spring and autumn. Surface and bottom samples were taken at each sampling point. The surface samples were taken in the dams within the first metre of water and the bottom samples within the first metre from the bottom of the dam. Samples were stored in transparent 350 mL plastic bottles and all the bottles were free of headspace where air could be trapped. A combination of new and re-used bottles was used. Both type of bottles were thoroughly washed and rinsed with the particular dam's water to eliminate the possibility of contamination with water from other research sites. The samples were immediately stored in a cooler container at temperatures below -5 °C. The samples were delivered to an accredited water analysis laboratory (BEMLAB in Somerset West) the same day or early the following day (Lind, 1979; Wetzel & Likens, 2000).

The following list of parameters was included for analysis:
Depth, Secchi disk, Temperature, Dissolved Oxygen (DO), pH, Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Chloride (Cl), Carbonate, Bicarbonate, Manganese (Mn), Copper (Cu), Zinc (Zn), Boron (B), Total phosphorous (TP), Orthophosphate (PO_4), Total Ammonia Nitrogen (TAN), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N), Aluminium (Al), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Alkalinity, Hardness, Sulphate. Although all the listed parameters, except depth, can conceivably be influenced by rainbow trout farming (hereafter called trout farming), the underlined parameters should increase most in association with trout farming (C.E Boyd, personal communication, 10 August 2012). 'Table 3.2 provides a summary of the parameters measurements with methods applied.

Table 3.2. Summary of parameters measured with methods applied (NA = not applicable)

Parameter	Unit	Method	Reference
Temperature	°C	Oxyguard MK III oxygen meter	OxyGuard International A/S
Turbidity	cm	Secchi disk (diameter 25 cm)	(Wetzel & Likens 2000)
DO	mg/L	Oxyguard MK III oxygen meter	OxyGuard International A/S
DO Saturation	%	Oxyguard MK III oxygen meter	OxyGuard International A/S

Water depth	m	Measuring tape with a weight at lower end	Division o f Aquaculture, SU
pH	NA	Hanna pH 211 microprocessor	Hanna Instruments Woonsocket, RI, USA
Hardness	mg/L	Complexometric titration with 0.01 M EDTA (method 2340c)	APHA et al., (2005), USEPA approved
Alkalinity	mg/L	Complexometric titration with 0.02N H2SO4 (method 2320)	APHA et al., (2005), USEPA approved
Ferrous iron	mg/L	1,10-Phenanthrolite Method	Stucki (1981), APHA et al., (2005)
Sulphate	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998
TSS	mg/L	Photometric Method	Hach Company, Loveland, CO, USA
Total P	mg/L	Molybdo-vanadate Method (unfiltered, acid digested sample)	APHA et al., (2005), USEPA approved
Orthophosphate	mg/L	Molybdo-vanadate Method (filtered sample)	APHA et al., (2005), USEPA
Nitrate	mg/L	Water determination using auto-analyser	Clesceri et al.(1998)
Nitrate	mg/L	Water determination using auto-analyser	Clesceri et al.(1998)
Ammonia	mg/L	Water determination using auto-analyser	Clesceri et al.(1998)
Sodium	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Potassium	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Calcium	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Magnesium	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Chloride	mg/L	Standard method	Clesceri et al.(1998)
Carbonate	mg/L	Standard method	Clesceri et al.(1998)
Bicarbonate	mg/L	Standard method	Clesceri et al.(1998)
Boron	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Copper	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Manganese	mg/L	Preparation of solution by ICP-OES elements	Clesceri et al.(1998)
Aluminium	mg/L	Atomic emmission with Varian ICP-OES	Clesceri et al.(1998)
TDS	mg/L	Conductivity meter	Crison Conductimeter GLP 32

Phytoplankton samples were also collected in duplicate at the sites (each dam) at the following times:

Sample 1, taken during the spring season of 2010.

Sample 2, taken during the summer season of 2011.

Sample 3, taken during the autumn season of 2011.

Sample 4, taken during the winter season of 2011.

Sample 5, taken during the spring season of 2011.

The samples were collected by inserting a 2 m long tube with a weight on the end to cut a 2 m deep phytoplankton sample from the surface of the water (Harding, 1992). All the samples were collected in more or less the same area as for the water quality analysis. Phytoplankton samples were fixated in the field and Lugol's acetic solution (1 mL to 100 mL of sample) was added for preservation and dyeing of the planktonic material (Lind, 1979; Entwisle et al., 1997; Hötzel & Croome, 1999). Samples were stored in a cool, dark place until identification and quantification were carried out. Samples were shaken vigorously to ensure proper mixing of material before decanting 20 mL of the sample into a self-constructed chamber (2 mL). The chambers with the sample were then allowed to settle for 24 h. After settling, cell counts and species identification by group and genus were done (Utermöhl, 1958; Van Vuuren et al., 2006; Van Ginkel et al., 2007). A Zeiss inverted microscope with a 100 x oil immersion objective was used for the cell counts and species identification (Young, 1986; Wetzel & Likens, 2000). The biovolume of each specimen was taken from the literature or calculated via the nearest geometrical shape. Biomass was calculated from the volume data using factors of 1.02 to 1.30 kg/m^3 (Sommer, 1996).

Data were analysed statistically by an analysis of variance (ANOVA) for repeated measures at the same site at different times (Steel & Torrie, 1980). It was generated using PROC LOGISTIC of SAS software, Version 9.3 of the SAS System for Windows (SAS, 2010). Differences were considered statistically significant if $p<0.05$. All means are given with ± standard error (S.E.). The data for the phytoplankton was not homoscedastic (equal variances) or normally distributed and therefore it was not possible to analyse it with ANOVA or general linear models. Therefore non-parametric methods were used and a logistic regression analysis per group with genus, geographical location and season as dependent variables in the model, was conducted. A total of 2600 observations and six groups were used for the statistical analysis. A separate analysis was done per group including genus, geographical location and season as dependent variables in the model. For purposes of analysis the group Cryptophyta was omitted for it had only genus. Production data were only captured from the small-scale fish farmers in 2009. Of the 29 sites, 15 trout farms could provide a full set of data. The production data of the selected fish farms were compared with water quality parameters. An ANOVA was performed where the yield (total kg of fish harvested) was run against the physico-chemical parameters (DO, pH, TAN, PO_4 and Secchi) and production data (fingerling source, date of stocking, date harvested, days in water, kg stocked, average stocking weight, average harvested weight, number of fish stocked, number of fish harvested, fish mortalities, FCR and SGR). Production data of fifteen rainbow trout farms for 2009 with associated physico-chemical water quality parameters are presented in Appendix 3.

A Principal Component Analysis (PCA) biplot was used to graphically depict all the sites and measured variables with the purpose of trying to see whether the fish farming and non-fish farming ones showed any groupings and how the sites are related to the measured variables (Gower et al., 2011). The PCA, a variable reduction method, was used to reduce the original, observed variables into a smaller number of artificial variables (principal compponents) that describe most of the variance in original variables. This method was used to highlight between group differences (fish farm and non-fish farm).

3.5. Results and discussion

The results of the analysis of specific parameters for both fish farmed and non-fish farmed dams are discussed in this section. First the group of parameters most likely not be influenced by the presence of aquaculture is discussed and thereafter the group most likely be influenced. The range of specific parameters (the minimum, maximum, mean and standard deviation) is shown in Table 3.3. The summary of the LSM values with standard errors are indicated in Table 3.4. The summary of ANOVA (Wald F-statistics & p-values) for physico-chemical parameters is shown in Table 3.5. All the water quality parameters are discussed, starting with a basic description, occurrence and possible pathways of entering water systems. Through the discussion reference is made of the interaction of the prevailing agricultural activities and its role and function in nutrient loading. It emphasizes that irrigation water bodies are dynamic systems undergoing seasonal changes in its physical and chemical character.

3.5.1 Parameters most likely not to be influenced by the presence of aquaculture

a. Depth

The depth of the dam used for cage culture is usually determined by the suspended length of the cage bag in whether it can hang freely without touching the bottom. A minimum depth of less than 1.20 m (see Table 3.3.) is unlikely to support any form of cage culture, except when this depth was recorded during or just after the summer season when trout farming is not taken place. Irrigation dams are primarily used for the summer irrigation of agricultural plant crops when the rainfall is relatively low or absent. The research was conducted in a winter rainfall area (Mediterranean) when dams are filled. The same dam will serve as a dam for irrigation during the summer. The minimum depth will increase as the dam fills, but huge fluctuations are not conducive to trout farming.

A maximum depth of 21.60 m (see Table 3.3) results in a slower environmental impact for larger, deeper water bodies have greater capacity for physical buffering against changes (Baily-Watts & Duncan, 1981). Fish farmers making use of cage culture appreciate deeper dams. The depth of dams ranged between 6-10 m. The mean value of 7.65 ± 3.27 m indicated that most of the selected dams were deep enough to support the cage culture of trout. The widely used net cages are usually suspended 4 m below the surface and require a free-space of at least 1 m for sufficient lateral flow through the netting (Beveridge, 2004; Salie et al, 2008). The physical criteria of water surface area and depth are important values for sustainable site selection. Maleri (2011) emphasized that fish farmers should understand the interaction of important site parameters (e.g. surface area, maximum dam depth, surface phosphorous concentrations, dominant rock type of the catchment area and dam basin) in order to minimise the impact of net-cage aquaculture.

No two sites will have the same depth. There is a statistically significant difference between sites for depth ($p<0.05$) as indicated in Table 3.5. Dams in the area range in sizes from small pond-like to larger water bodies such as lakes. However, compared to natural lakes, the range of dam types and morphological variation is generally much greater (Chapman, 1996). Usually dams were designed according to contours and draining channels, thus creating a unique bathometry for structure. The geology and soil type can also influence the dam design. The dams under research were all used for irrigation and the inflow and extraction dynamics resulted in fluctuating depths during the year.

During site selection for fish farming, the deeper dams (> 6 m) were always selected for fish farming. Therefore it was found that there is a statistically significant difference between fish farmed and non-fish farmed with regard to depth ($p<0.05$). Cage culture is based on the water body being deep enough to provide sufficient space underneath the suspended cages. This practice is beneficial for dispersing accumulated waste under the cages through lateral movement and flow of the water. It has been found that deeper dams have a greater chance of successfully hosting sustained fish farming than shallower dams as the volume is larger and the capacity to diffuse oxygen increases (Isyagi et al., 2009). The bottoms of dams are generally associated with anoxic conditions and can be detrimental to fish farming if regular mixing does not occur. Therefore it is important for fish farmers to understand the dynamics of the prevailing stratification patterns in their dams and what needs to be done to manage it.

Table 3.3. Twenty eight physico- chemical water parameters with the overall range of variation, mean and standard deviation, for the 29 sampled dams (*n*=524).

	Range of variation			
Parameter	**Min**	**Max**	**Mean**	**Standard deviation**
Depth (m)	1.20	21.60	7.65	3.27
Secchi disk (cm)*	10	510	139	94
Temperature (ºC)	6.20	28.30	16.48	4.78
Dissolved Oxygen (mg/L)*	0.30	16.40	8.07	2.49
pH	4.50	9.20	7.11	0.85
Total Dissolved Solids (mg/L)	4.00	550	101.4	94.88
Sodium (mg/L)	1.56	105.30	16.27	14.60
Potassium (mg/L)	0.06	9.11	1.74	1.46
Calcium (mg/L)	0.07	38.42	5.77	6.58
Magnesium (mg/L)	0.11	23.63	3.86	3.83
Iron (mg/L)	0.010	14.380	0.453	1.205
Chloride (mg/L)	0.18	251.60	30.50	26.93
Carbonate (mg/L	9.04	330.70	7.68	32.15
Bicarbonate (mg/L	3.06	180.30	29.11	24.03
Sulphate (mg/L)	0.300	86.390	8.081	10.280
Boron (mg/L)	0.010	0.150	0.018	0.016

Manganese (mg/L)	0.001	2.199	0.066	0.235
Copper (mg/L)	0.001	0.083	0.003	0.007
Zinc (mg/L)	0.001	0.141	0.011	0.018
Phosphorous (mg/L)*	0.001	0.735	0.065	0.223
Total Ammonia Nitrogen (mg/L)*	0.015	6.480	0.475	0.682
Orthophosphate (mg/L)*	0.003	2.253	0.198	0.684
Nitrate-Nitrogen (mg/L)*	0.009	7.360	0.535	0.851
Nitrite-Nitrogen (mg/L)*	0.001	0.200	0.024	0.024
Aluminum (mg/L)	0.010	1.014	0.233	0.232
Total Suspended Solids (mg/L)*	2.00	1396	53.28	114.40
Alkalinity (mg/L)	1.51	92.87	20.23	20.60
Hardness (mg/L)	1.89	98.07	26.85	25.74

*** -** parameters most likely to be influenced by aquaculture

Table 3.4. The comparison of physico-chemical water parameters with LSM and standard errors for non-fish farmed and fish farmed sites (*n*=684). The ratio of fish farming (FF) to non-fish farming (NF) is indicated.

Parameters	**Non-fish farming (NF)**		**Fish farming (FF)**		**Ratio of FF to NF**
	LSM	Standard error	LSM	Standard error	
Secchi disk (cm)	116	5	147	4	1.27
Temperature (ºC)	15.85	0.31	17.18	0.24	1.08
Dissolved Oxygen (mg/L)	8.21	0.148	8.09	0.12	0.99
pH	6.54	0.04	7.28	0.03	1.11
Sodium (mg/L)	13.45	0.61	17.15	0.47	1.28
Calcium (mg/L)	4.80	0.31	6.37	0.24	1.33
Magnesium (mg/L)	3.25	0.13	4.06	0.10	1.25
Iron (mg/L)	0.59	0.11	0.68	0.09	1.15
Chloride (mg/L)	26.32	1.22	32.31	1.07	1.23
Carbonate (mg/L	0.17	3.18	12.11	2.62	71.24
Bicarbonate (mg/L	26.94	1.23	30.60	1.00	1.14
Sulphate (mg/L)	10.589	0.668	6.980	0.387	0.64
Boron (mg/L)	0.020	0.002	0.020	0.001	1.00
Manganese (mg/L)	0.042	0.016	0.087	0.013	2.07
Copper (mg/L)	0.002	0.001	0.002	0.001	1.00
Zinc (mg/L)	0.012	0.002	0.012	0.002	1.00
Phosphorous (mg/L)	0.049	0.011	0.101	0.021	2.06
Orthophosphate (mg/L)	0.185	0.042	0.168	0.034	0.91
Total Ammonia Nitrogen	0.593	0.088	0.476	0.050	0.80
Nitrate-Nitrogen (mg/L)	0.493	0.073	0.503	0.057	1.02
Nitrite-Nitrogen (mg/L)	0.017	0.002	0.023	0.001	1.35
Aluminum (mg/L)	0.245	0.014	0.245	0.014	1.00

Total Suspended Solids	23.76	7.86	55.94	6.75	2.35
Total Dissolved Solids	69.47	4.54	99.34	3.76	1.43
Alkalinity (mg $CaCO_3$/L)	23.93	2.81	23.47	1.29	0.98
Hardness (mg $CaCO_3$/L)	26.80	1.15	26.63	1.80	0.99

b. Temperature

Temperature, together with DO, are the two most important water quality parameters to consider when choosing sites for fish farming and predetermining the chances of sustainable production and culture success (Pillay & Kutty, 2005; Maleri, 2008). Fish are poikilothermic animals, therefore their rate of metabolism, growth, energy consumption and absorption of nutrients are strongly influenced by their surrounding water temperature (Hinshaw, 1990; Azevedo, 1998). Trout prefer temperature ranges of 9-18 ºC for optimal growth in Mediterranean conditions (FAO, 2011). The spread of this range over the year will determine the number of months available for production. A minimum water temperature reading of 6.20 ºC is slightly below the lower limit for good trout farming, thus this can result in a decrease of oxygen uptake due to the slowing metabolism.

Table 3.5. The influence of surface or bottom sampling location, different sites and whether there was fish farmed or not on the physico-chemical parameters in different dams. Differences are considered statistically significant if $p<0.05$ (ANOVA, Wald F-statistics). The light grey coloured rows indicate significant differences.

Parameter	**Source of variation**	**F-value**	**P-value**
Depth	Surface/Bottom	0.00	Not Applicable (NA)
	Site	21.51	<0.001
	Fish farmed/Non-fish farmed	15.94	<0.001
Secchi	Surface/Bottom	NA	NA
	Site	14.49	<0.001
	Farmed/Non-fish farmed	27.77	<0.001
Dissolved oxygen	Surface/Bottom	161.56	<0.001
	Site	2.39	<0.001
	Farmed/Non-fish farmed	0.38	0.535
Oxygen saturation	Surface/Bottom	162.78	<0.001
	Site	2.47	<0.001
	Farmed/Non-fish farmed	0.10	0.747
pH	Surface/Bottom	7.12	0.008
	Site	22.60	<0.001
	Farmed/Non-fish farmed	192.53	<0.001
Sodium	Surface/Bottom	3.80	0.054
	Site	71.02	<0.001
	Farmed/Non-fish farmed	21.06	<0.001
Potassium	Surface/Bottom	1.38	0.244
	Site	60.81	<0.001
	Farmed/Non-fish farmed	18.07	<0.001

Calcium	Surface/Bottom	2.33	0.130
	Site	50.61	<0.001
	Farmed/Non-fish farmed	14.67	<0.001
Iron	Surface/Bottom	34.98	<0.001
	Site	2.35	<0.001
	Farmed/Non-fish farmed	0.34	0.556
Chlorine	Surface/Bottom	0.81	0.369
	Site	47.57	<0.001
	Farmed/Non-fish farmed	12.23	<0.001
Sulphate	Surface/Bottom	3.30	0.072
	Site	18.32	<0.001
	Farmed/Non-fish farmed	19.64	<0.001
Boron	Surface/Bottom	5.51	0.020
	Site	4.19	<0.001
	Farmed/Non-fish farmed	0.01	0.937
Manganese	Surface/Bottom	3.31	0.072
	Site	15.39	<0.001
	Farmed/Non-fish farmed	4.07	0.046
Copper	Surface/Bottom	0.16	0.684
	Site	1.27	0.165
	Farmed/Non-fish farmed	0.02	0.889
Zinc	Surface/Bottom	0.69	0.405
	Site	1.04	0.417
	Farmed/Non-fish farmed	0.01	0.912
Phosphorous	Surface/Bottom	6.51	0.012
	Site	1.64	0.022
	Farmed/Non-fish farmed	4.44	0.037
Orthophosphate	Surface/Bottom	6.39	0.012
	Site	1.46	0.061
	Farmed/Non-fish farmed	0.09	0.762
Total Ammonia Nitrogen	Surface/Bottom	8.98	0.003
	Site	1.08	0.353
	Farmed/Non-fish farmed	1.19	0.277
Nitrate-Nitrogen	Surface/Bottom	2.30	0.132
	Site	1.31	0.135
	Farmed/Non-fish farmed	0.01	0.914
Nitrite-Nitrogen	Surface/Bottom	17.39	<0.001
	Site	2.90	<0.001
	Farmed/Non-fish farmed	9.17	0.003
Aluminium	Surface/Bottom	1.06	0.309
	Site	9.52	<0.001

	Farmed/Non-fish farmed		
Total suspended solids	Surface/Bottom	0.43	0.509
	Site	1.63	0.025
	Farmed/Non-fish farmed	8.90	0.003
Total dissolved solids	Surface/Bottom	8.35	0.004
	Site	26.60	<0.001
	Farmed/Non-fish farmed	23.34	<0.001
Alkalinity	Surface/Bottom	8.07	0.005
	Site	32.36	<0.001
	Farmed/Non-fish farmed	0.02	0.873
Hardness	Surface/Bottom	0.26	0.609
	Site	33.37	<0.001
	Farmed/Non-fish farmed	0.01	0.934

The maximum value of 28.30 ºC is well above the upper limit for trout production, and is indicative of water temperatures for summer months (see Table 3.3). The nature of the Mediterranean climate lends itself to a limited period of trout production for most of the experimental sites. It is sometimes possible to farm trout at elevated sites, such in Ceres (Koue Bokkeveld) where summer water temperature seldom rises above 21 ºC. The mean value of 16.48 ± 4.78 ºC is within the optimal temperature range where trout has the lowest mortality rates and highest growth rate (Figure 3.6).

The LSM values for non-fish farmed and for fish farmed reservoirs are 15.85 and 17.18 respectively (see Table 3.4). The small difference in temperatures is expected to have a negligible effect on the overall trout performance. Both values are within the temperature range for trout farming (about 7–18 °C), where the appetite of the fish is optimal (Woynarovich et al., 2011).

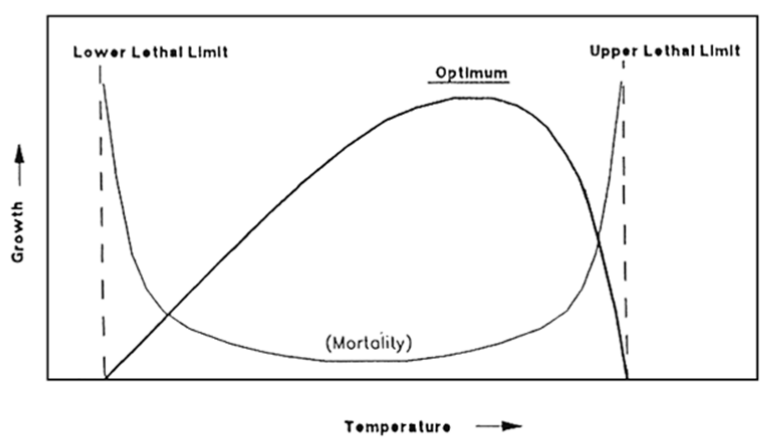

Figure 3.6. The relationship between fish growth and temperature (Akrout & Belkhir, 1994).

c. pH

There are different pH levels required for different stages in the life cycle of trout. For developing and embryo stages 6.5 to 8 are proposed and for older fish the range can be wider (FAO, 2011). The minimum pH value of 4.50 is not conducive to trout farming (see Table 3.3) for trout prefer pH values of 6-9 for optimal growth (DWAFF, 1996 B). The maximum of 9.20 is also slightly outside the optimum range. The mean pH for the total number of sites is 7.11 ± 0.85. The above-mentioned fluctuations are indicative of a water resource weakly buffered to withstand pH fluctuations (Kristensen et al., 2009). They can also have a secondary effect on the toxicity levels of other parameters such as ammonia which becomes more toxic with an increase in pH and temperature. The mean pH value of 7.11 ± 0.85 is in the desirable range for successful trout farming. Although the maximum value is relatively high for freshwater bodies, it is in line with the highest value of 9.38 which Maleri (2011) found in her study.

The LSM value of 6.54 for the pH of the non-fish farmed sites was significantly lower compared to those for fish farmed sites which had a LSM value of 7.28 (see Table 3.4). In non-fish farmed sites the pH of water can be influenced by waste water (storm, sewage, industrial), inorganic constituents (from surrounding soils) and acid rain (Factors that affect the pH of water in wetlands, [s.a.]). In fish farmed sites the pH changes can be ascribed to organic loading via fish farming in addition to the same influences for non-fish farmed sites. Fluctuating pH values in dams are usually due to changes in the OH^- or H^+ ion concentration in the water, and both concentrations associated with non-fish farmed and fish farmed sites can contribute to these concentrations. This is a reasonable initial assumption, given that photosynthesis causes pH to rise, whereas respiration causes pH to decline due to usage and production of CO_2. In cases where a lot of sunlight and healthy algal populations are present, photosynthesis predominates over respiration, thus resulting more often in an alkaline environment and rise in pH ((Lewis & McCutchan, 2009). Thus, the higher value in the fish farmed sites could most likely be attributed to an increase in algal growth as a result of increased nutrient. The algae can increase the utilization of CO_2.

The results indicate a significant difference in pH ($p<0.05$) between the surface and bottom (see Table 3.5). The bottom of a dam is characterised by both inorganic and organic sediment accumulation. In monomictic dams where regular mixing does not occur, NH_3, H_2S and CO_2 increases in the bottom layer due to anoxic conditions and lowers the pH of the hypolymnion. The pH shifting between acid and alkaline ranges is a dynamic process in dams, thus presenting differences among sites ($p<0.05$). The microclimate (precipitation and evaporation) as well as geology of the dam can also result in different values for sites. The difference in pH in dams with and without fish farming activities can be linked to the secondary effect fish farming has on the values ($p<0.05$). An increase in nutrient loading, specifically in N and P, can result in excessive algal growth in a freshwater body. High algal biomass release carbon dioxide through respiration or use it during photosynthesis. The fluctuating CO_2 concentrations influence the pH levels. Another contributing factor is the built-up of organic waste as sediment on the dam floor. This is associated with cage culture where the net cages are not routinely rotated and instead of gradual dispersal, waste accumulates in one area. Under anoxic conditions H_2S and CO_2 are released and this influences the pH. In other studies it was found that trout farming has no significant impact on the pH values (Cornel & Whoriskey, 1993; Pulatsu et al., 2004; Maleri, 2011). However, when comparing the LSM of dams with and without fish farming activities, there was a significant difference and fish farmed dams exhibit a lower value (6.54) than non-fish farmed dams (7.28). The LSM values for alkalinity were 23.9 and 23.5 for farmed and non-fish farmed dams respectively. Alkalinity values < 75 mg/L have a low buffering capacity and lead to fluctuating pH levels. The desired total alkalinity level for most aquaculture species lies between 50-150 mg/L $CaCO_3$, but should not be less than 20 mg/L (Wurts, 2002).

d. Total dissolved solids (TDS)

Total Dissolved Solids (TDS) is a measurement of inorganic salts, organic matter and inorganic constituents in the water (USEPA, 1986; IDPH, 2012). The solids can include chlorides, sulfphates, calcium and other inorganic constituents found on the earth's surface. The dissolved inorganic constituents can produce an unpleasant taste or appearance and can contribute to scale deposits on piping and conduits in aquaculture systems. TDS is also an indication of the salinity of the water environment. "The mean salinity of the world's rivers is approximately 120 mg/L and the major anion found in natural waters is bicarbonate" (Weber-Scannell & Duffy, 2007). Day and King (1995) indicated that ground waters in the southern and south-western Cape low in TDS (< 1000 mg/L). The mean of 101.40 ± 94.88 mg/L is close to the world average for rivers and natural waters. Natural water with concentrations > 1000 mg/L is described to be brackish (Weber-Scannell & Duffy, 2007). The range of TDS values from a minimum of 4.00 mg/L to a maximum of 550 mg/L is indicative of waters that are not saline (see Table 3.3). This result presented a wider habitat range and production opportunities for both stenohaline (e.g. common carp) and euryhaline (e.g. trout) as aquaculture species. Higher levels > 1000 mg/L can also lead to a decrease in the propagation of wetland plants such as *Typha* species, thus reducing plant biomass. Derry et al. (2003) reported that salinity concentrations of the water and aquatic biodiversity are inversely associated. Wetland plant species are important for treating aquaculture effluent in the post-farm zone (area of river course below the dam). Here harmful accumulated ammonia can be broken down into less harmful compounds such as nitrate through nitrification and the functioning of a colony of mesophyllic, aerobic bacteria including the genera of *Nitrosomonas* and *Nitrobacter spp*.

The LSM value of 69.47 mg/L for the non-fish farmed site is lower than the value of 99.33 mg/L for fish farmed sites (see Table 3.4). This is in line with the values explained by Mirrasooli et al., (2012). They found in their study that farm effluent has a significant effect on the TDS concentration. Dissolved organic carbon, in the form of humic acids derived from decaying vegetable matter may also contribute to TDS (DWAF, 1996 B). This chemical process is the cause of the characteristic brown colour to the WCP's freshwater in rivers and dams.

The statistically significant difference between TDS ($p<0.05$) at the surface and at the bottom could be due to solids containing inorganic constituents trapped in the sediment (see Table 3.5). The total dissolved solids test measures the total amount of dissolved inorganic constituents in water. This could be the reason for the higher concentration in the bottom layers of the dam. The difference in sites could be due to external environmental aspects such as geology, soil types and source and pathway of effluents entering the water body.

The statistically significant difference between fish farms and non-fish farms ($p<0.05$) is unlikely to be linked to fish production (C.E Boyd, personal communication, 10 August 2012). A possible explanation has been discussed, with reference to Mirrasooli et al., (2012).

e. Sodium (Na)

Sodium is present in most freshwater bodies and concentrations may vary considerably from freshwater to brackish water. Most water supplies contain less than 20 mg/L of sodium, but there are instances where recorded levels exceeded 250mg/L in water supplies of some countries (Priyadarshi, 2005). The target water quality range for no adverse effect on livestock is between 0-2000 mg/L (DWAF, 1996 A). The mean value of 16.27 ± 14.60 mg/L is comparable to the value of 20 mg/L for most freshwater supplies in the world. The minimum reading of 1.56 mg/L and a maximum of 105.30 (see Table 3.3) is within water quality parameters for freshwater fish species, especially rainbow trout which can be rapidly transferred to two-thirds seawater and survive with gradual acclimation. Fish bred in water within this range have a low mortality rate and adapt within 7– 10 days (Landless, 1976; Bath & Eddy, 1979). Freshwater fish are hypertonic to their water environment and water continually diffuses into the fish through the gill membranes and into the blood. It has to secrete copious amounts of dilute urine to maintain osmoregulation. Higher concentrations of sodium can increase the energy requirement of fish for osmoregulation and affects overall growth performance of fish in production systems (Baldisserotto et al., 2007).

The lower value of 13.45 mg/L for non-fish farmed sites compared with the value of 17.15 mg/L for farmed sites could be due to Na leaching from uneaten feeds, and the accumulation of excretory products.

There was no statistically significant difference in Na ($p>0.05$) concentration between the surface and bottom of dams. There is significant difference in the Na concentration among sites ($p<0.05$). All the farm irrigation dams were different in physical and chemical structure for aspects such as underlying geology, soil types, main water supply and surrounding vegetation are considered before the construction of dams (Butler, 2011). The difference in sodium concentration for farmed and non-fish farmed sites ($p<0.05$) could be ascribed to the accumulation of and subsequent organic enrichment via metabolic waste and excess feeds. Fish mortality could also contribute to increasing sodium levels in instances where dead fish are not regularly removed from the net cages by the farmers. Fish mortality rates are usually about 2-3 % of the population, with many of the fish actually dying after handling during harvesting and test sampling (Kayim et al., 2007; Salie et al., 2008).

f. Potassium (K)

Potassium plays an important role in plant growth. “Potassium from dead plant and animal material is often bound to clay inorganic constituents in soils, before it dissolves in water and is readily taken up again by plants” (Water treatment solutions, [s.a.]). The maximum value of 9.11 mg/L, as well as the mean value of 1.74 ± 1.46 mg/L (Table 3.3) is within the range for natural freshwaters.

There was no statistically significant difference between the amounts of potassium ($p>0.05$) at the surface and at the bottoms of dams. The statistically significant difference in K concentration $p<0.05$) between dams could be explained by the heterogeneity of the landscape and spatial utilization where these farm dams were constructed. Each site has its own natural, climatic, anthropogenic and agricultural influences, and the interaction of these aspects is the reason for the homogeneity of the individual sites (Kumar et al., 2006; Butler, 2011).

The statistically significant difference between fish farmed and non-fish farmed with regard to K could be explained by the accumulation of organic material ($p<0.05$). Although the K values for fish farmed sites are higher than for non-fish farmed sites, the maximum as well as the mean values are well below the range for natural fresh waters. Asante et al., (2008) also support the idea that excessive levels could be indicative of organic contamination of the water resource.

g. Calcium (Ca)

Calcium concentrations derive from geological processes and fertilizer applications, and generally do not present high values in the water. In some places the climate is more prominent in influencing levels than the effect of geology. Typically, the concentration of calcium in freshwater is 15 mg/L (DWAF, 1996 A). The minimum value of 0.07 mg/L is indicative that this dam has been constructed on a granite geological formation. Many waters from limestone areas may contain 30-100 mg/L Ca and those associated with gypsiferous shale may contain several hundred mg/L. The maximum value of 38.42 mg/L is within the range for limestone areas. Calcium contributes to the total hardness of water and functions as a pH stabilizer due to its buffering capacity (Bartram & Balance, 1996). “It is also important as it protects freshwater fish against osmotic and ionic gains and losses, as well as against most environmental toxicants” (Çalta, 2000). Fish can absorb Ca directly from the environment or from food to serve these requirements. The mean reading of 5.77 ± 6.58 mg/L for the sites is too low to provide any improvement in water quality for fish species. The acceptable range for Ca concentrations for aquaculture is 25-100 mg/L, which is equal to 63-250 mg/L $CaCO_3$ hardness (Wurts, 2000). “Many algae species including *Chlamydomonas* and euglenoid species also thrive at a Ca concentration of 16.78 mg/L” (Moss, 1973).

Most rainbow trout diets contain about 2-2.5 % Ca during starter, juvenile and production phases. Calcium can leach from uneaten feeds. The difference in LSM values for farmed (6.37 mg/L, standard error 0.24) and non-fish farmed (4.80 mg/L, standard error 0.31) dams is attributed to the influence of uneaten feed in surrounding waters. The Ca concentration can also increase in areas where water losses are excessive due to evaporation causing an increase in the salt concentration of the water. Evaporation can be as high as 300 mm over the summer months (Dec-Feb) at the WCPs’ major dams (Western Cape water supply systems, [s.a.]).

There was no statistically significant difference between surface and bottom readings for Ca ($p>0.05$). The statistically significant difference between sites ($p<0.05$) with regard to Ca concentration could be explained by the heterogeneity of the landscape and spatial utilization where these farm dams were constructed. Each site had its own natural, micro-climatic, anthropogenic and agricultural influences, including geological formations and soil types and therefore one would expect different concentrations of Ca among the sites. The dynamics of these different factors that could occur in varying degrees have already been described (refer to Kumar et al., 2006; Butler, 2011).
Results indicated a significant difference in Ca concentration between dams where fish are farmed and those where no farming takes place ($p<0.05$). Although not conclusive, this phenomenon could possibly be ascribed to the biological activities of the fish as well as excess feeds. The difference in LSM values for farmed and non-fish farmed dams is too low to affect fish production.

h. Magnesium (Mg)

“The Mg concentration in South African freshwater is generally between 4-10 mg/L“ (DWAF, 1996 A). The mean value of 3.86 ± 3.83 mg/L indicates that most of the sites are in predominantly granite or siliceous soils. Water in contact with dolomite or magnesium-rich limestone may contain 10-50 mg/L, and several hundred mg/L may be present in water that has been in contact with deposits containing sulphates and chlorides of magnesium. The maximum value of 23.63 mg/L is within this range. Magnesium also affects the hardness of water, and thus the buffering capacity of the water (Bartram & Balance, 1996).

The LSM value for non-fish farmed sites was 3.25 mg/L (standard error 0.13) and 4.06 (standard error 0.10) for fish farmed sites. There is no significant difference between the Mg concentrations for farmed and non-fish farmed sites.

i. Iron (Fe)

“The form and solubility of iron in natural waters are strongly dependent upon the pH and the oxidation-reduction potential of the water and in a normal pH range of 6 to 9 rarely carry more than 1 mg/L dissolved iron” (Bartram & Balance, 1996). In South Africa unpolluted surface water contains between 0.001-0.5 mg/L (DWAF, 1996 A). “Iron as it exists in natural groundwater is in the soluble (ferrous) state but, when exposed to oxygen, it is converted into the insoluble (ferric) state with its characteristic reddish brown or rusty colour” (IDPH, 2012). The following levels of iron (Fe) are expressed in mg/L (IDPH, 2012): 0 - 0.3 is acceptable, 3 - 1.0 is satisfactory (however, may cause staining and objectionable taste) and >1.0 is considered as unsatisfactory.

The maximum value of 14.38 mg/L is extremely high, and most probably an outlier. Other high values recorded were 5.93, 5.93 and 10.71 mg/L. According to DWAF (1996 A), values of <0.01 mg/L have no effect on fish and the range of 0.01-0.50 mg/L is an indication of unpolluted surface water. All the above high readings were taken in the bottom layers of the dams, although the mean value is 0.453 ± 1.205 mg/L.

The statistically significant difference between surface and bottom concentrations of Fe ($p<0.05$) could be indicative of the heavy metals released from the sediment of dams. Under anoxic/reducing conditions metals can dissolve more readily and such metals introduced into the dam may be adsorbed to clay particles, organic matter and silt in the sediment and gradually released into the water column. Lee et al., (2008) found that “trace metals such as Fe, Al and Mn adsorb to suspended metal hydroxides and are ultimately discharged into dams or lakes and thus affect the chemical composition of water and sediment”. Their study further indicated that a slight decrease in the pH of the sediment pore water from 6.4 to 5.9 resulted in a noticeable release of trace metals into the environment. The statistically significant difference between sites with regard to Fe concentration ($p<0.05$) could be explained by the heterogeneity of the landscape and spatial utilization where the farm dams were constructed. Dams are influenced by several extrinsic factors which may alter the structural and functional components of the ecosystem. Thus, each site in the study has its own natural, climatic, anthropogenic and agricultural influences. The dynamics of these different factors that can occur in varying degrees have already been described (refer to Kumar et al., 2006; Butler, 2011; Goswami, 2012).

j. Chloride (Cl)

“Chloride anions are usually present in natural waters that have been in contact with chloride-containing geological formations” (Bartram & Balance, 1996). High chloride concentrations may also indicate pollution by sewage or industrial effluent or as a result of the influx of saline water into a freshwater body. “A salty taste in water depends on the ions with which the chlorides are associated. With Na ions the taste is detectable at about 250 mg/L Cl, but with Ca or Mg the taste may be undetectable at 1,000 mg/L. High chloride content has a corrosive effect on metal pipes and structures and is harmful to most trees and plants” (Bartram & Balance, 1996). Chlorides in groundwater can be naturally occurring in deep aquifers or caused by pollution from sea water, brine, or industrial or domestic wastes. Most freshwater species can survive comfortably at approximately 500 mg/L of Cl (DWAF, 1996 B). The maximum reading of 251.60 mg/L as well as the mean of 30.50 ± 26.93 mg/L are well within the range that will support the survival of freshwater organisms. The following levels of chlorides are expressed in mg/L (IDPH, 2012) and the classification is as follows: 0 - 250 is acceptable, 250 - 500 is lower than desirable, 500 - 1000 is undesirable and > 1000 is unsatisfactory.

There was no statistically significant difference between surface and bottom concentrations of Cl ($p>0.05$). The LSM value for non-fish farmed sites was 26.32 mg/L with a standard error of 1.22. The value for the farmed sites was 32.31 mg/L with a standard error of 1.07. Although there is a statistical difference in Cl readings between farmed and non-fish farmed dams ($p<0.05$), the difference in LSM values indicates that the impact on the water quality is more or less similar. The statistically significant difference between sites ($p<0.05$) could be result of prevailing geochemistry where soil types can contain different levels of Cl or concentrations of Fe.

k. Carbonate (CO_3)

“The carbonate/bicarbonate interaction is fundamental to the maintenance of H+ concentrations, and therefore pH levels in a solution, and therefore, the concentration of carbonate/bicarbonate complexes are controlled to a large extent by the presence or absence of Ca and Mg, and these in turn help moderate, or buffer pH” (Kelly, 1998). There is a huge fluctuation between the minimum (9.00 mg/L) and the maximum (330.70 mg/L) concentration of CO_3 and this could be as a result of weakly buffered water. The mean value is 7.68 ± 32.15 mg/L. The LSM for non-fish farmed sites is 0.17 mg/L (standard error 3.18) and for fish farmed sites it is 12.11 mg/L (standard error 2.62).

The fish farmed sites indicated a carbonate value of more than 12 times bigger and this can be ascribed to the secondary effect of fish farming. Enrichment caused by fish farming, together with the mesophyllic temperatures provides the ideal environmental cues for phytoplankton proliferation. CO_2, CO_3 and bicarbonates can be effectively utilized by plankton and could lead to increases in pH in waters with a weaker buffering capacity (Moss, 1973).

l. Bicarbonate (HCO_3)

Bicarbonate concentrations also play a role in the buffering capacity of water. The minimum reading was 3.06 mg/L and the maximum was 180.30 mg/L, with a mean value of 29.11 ± 24.03 mg/L.

The LSM value for non-fish farmed sites was 26.94 mg/L with a standard error of 1.23. The value for the farmed sites was 30.60 mg/L with a standard error of 1.00. There is no difference between the bicarbonate concentration for farmed and non-fish farmed sites ($p>0.05$). There is no statistically significant difference between surface and bottom concentrations of bicarbonate ($p>0.05$). There is a statistically significant difference between bicarbonate ($p<0.05$) readings at different sites. The statistically significant difference between sites have already been described (refer to K discussion). There is a statistically significant difference between bicarbonate readings ($p<0.05$) from fish farmed and non-fish farmed dams. The difference in LSM values has little influence on the chemical value of the water.

m. Manganese (Mn)

"Although manganese in groundwater is generally present in the soluble divalent ionic form because of the absence of oxygen, part or all of the manganese in surface waters (or water from other sources) may be in a higher valence state" (Bartram & Balance, 1996). In fish farming practices, faeces produced is regarded to have higher content of manganese, cadmium, chromium and lead and lower concentrations of arsenic and selenium compared to other animal faeces (Naylor et al., 1999). The presence of Mn concentrations can be found in anaerobic bottom waters, where it has been dislodged from sediments. The usual range for freshwater is 0.0002 – 0.130 mg/L and concentrations > 0.5 mg/L increases the risk of lethal effects (DWAF, 1996 B).The minimum reading was 0.001 mg/L and the maximum was 2.199 mg/L with a mean value of 0.066 ± 0.235 mg/L. The maximum value is relatively high and prolonged high concentrations can adversely affect fish species. Caution should be exercised by fish farmers for high levels of Mn can disrupt metabolic pathways i.e. sodium regulation in fish, and could fish mortalities (DWAF, 1996 B).

The LSM value for non-fish farmed sites was 0.042 mg/L with a standard error of 0.016. The value for the farmed sites was 0.087 mg/L with a standard error of 0.013. There is a statistically significant difference in Mn ($p<0.05$) concentrations between fish farmed and non-fish farmed dams. Although there is a difference between the two values, both were still below 2 mg/L. Values > 2 mg/L and could lead to changes in the water's physico-chemical properties (Gantzer et al., 2009). The concentration of Mn in the water column is directly associated with the concentrations of DO in the water column and it was observed that during oxygenation Mn was low in the hypolimnion (<0.05 mg/L), but high (> 2 mg/L) in the benthic region close to the sediment (Gantzer et al 2009). Soluble Mn can also persist until the bottom accumulation of organic debris through the hypolymnion layer increases. Thus, the difference between fish farmed and non-fish farmed dams can be explained by extrapolating that fish farming dams have a higher organic content due to higher detritus in the hypolymnion which arose from settling feed and faeces. Schenone et al., (2011) supported this phenomenon and also found higher concentrations of Mn and Zn in fish farm effluent. Although the hypolimnion can contain higher levels of Mn, the analysis indicated that there is no statistically significant difference between Mn ($p>0.05$) readings at the surface and the bottom layers of the dam. The statistically significant difference between sites has already been described (refer to previous discussion on geological and morphologically differences).

n. Boron (B)

“In most natural waters B is rarely found in concentrations greater than 1 mg/L, but even this low concentration can have deleterious effects on certain agricultural products, including citrus fruits, walnuts and beans” (Bartram & Balance, 1996). Soucek et al (2011) postulated that in natural freshwaters concentrations >1 mg/L can have a deleterious effect on most aquatic species. The minimum reading in dams involved in the research was 0.010 mg/L and the maximum was 0.150 mg/L. This indicated a mean value of 0.018± 0.016 mg/L. The maximum value is below the target range for sensitive aquatic species and has no adverse effect on trout.

The LSM value for non-fish farmed sites was 0.020 mg/L with a standard error of 0.0012. The value for the farmed sites was 0.020 mg/L with a standard error of 0.001. There is no statistically significant difference between B readings in fish farmed and non-fish farmed dams ($p>0.05$). The statistical significant difference between surface and bottom concentrations of B ($p<0.05$) could be the result of the release of the B as a trace metal trapped in the sediment of the dam. Thus, the bottom layer will have higher concentrations of B than the surface layer, unless mixing of the dam occurs, releasing higher concentrations in the water column. The statistically significant difference between sites has already been described (refer to previous discussion).

o. Copper (Cu)

“Copper is generally present in freshwaters, with cupric ion (Cu^{+2}) as the primary form in natural surface waters with typical concentrations ranging around 0.300mg/L” (DWAF, 1996 B). Cu concentrations in excess of 0.07 mg/L are considered to cause avoidance behaviour in rainbow trout (DWAF, 1996 B). The dietary requirement of Cu for rainbow trout has been reported to be 0.003 mg/L Cu g dry mass food (Ogino & Yang, 1980). Pathways of Cu to receiving waters can occur through copper mining activities, agricultural activities (e.g. mildew-cide, fungicide, and/or algaecide), and manufacturing activities (e.g., manufacturing of leather and leather products), (EPA, 2012). Although high levels of Cu can be ascribed to the usage of fungicide, the concentrations recorded at the research sites were low and not indicative of excessive usage of fungicide. The maximum value of 0.083 mg/L can lead to behaviour changes in trout, but the mean value of 0.003 ± 0.007 mg/L calculated across the study area is indicative that both fish farmed and non-fish farmed sites were well within the target ranges for fish farming.

The LSM for non-fish farmed sites was 0.002 mg/L with a standard error of 0.001. The value for the farmed sites was 0.002 mg/L with a standard error of 0.001, thus there was no statistically significant difference between fish farmed and non-fish farmed sites with regard to Cu ($p>0.05$). Furthermore, there was no statistical difference in Cu concentrations ($p>0.05$) between surface and bottom samples, as well as between sites.

p. Zinc (Zn)

Surveys of river water in Canada reported that Zn concentrations varied widely both with regard to location and season. However the the concentrations normally do not exceed 0.04 mg/L (Environment Canada. 1984). In South Africa, inland waters typically have concentrations of approximately 0.015 mg/L (DWAF, 1996 B). “Zn dietary requirements for rainbow trout are recommended to be between 15-30 mg/L” (Ogino & Yang, 1978). However, there is no real conclusion on dietary Zn levels toxic to rainbow trout (Read, 2012). Zinc toxicity increases with an increase in temperature, and a decrease in dissolved oxygen and may show avoidance behaviour (DWAF, 1996 B). The maximum recorded value of 0.141 mg/L and the mean value of 0.011 ± 0.018 mg/L are within the target ranges for salmonids (0.03 to 0.2 mg/L) under conditions where the water hardness is between 10-50 mg/L $CaCO_3$.

The LSM value for non-fish farmed sites was 0.012 mg/L with a standard error of 0.002. The value for the fish farmed sites was 0.012 mg/L with a standard error of 0.002. Thus, the results indicated that there is no statistically significant difference between surface and bottom readings for Zn ($p>0.05$), as well as no statistically significant difference between sites for Zn ($p> 0.05$) and also no statistically significant difference between fish farmed and non-fish farmed sites for Zn ($p>0.05$).

q. Aluminum (Al)

Aluminium occurs in many rocks, inorganic constituents and clays and is present in practically all surface waters. However, its concentration at neutral pH rarely exceeds a few tenths of a milligram per litre. It has been reported that there is no adverse effect on aquatic life at pH > 6.5 of Al concentrations of 0.03 mg/L. Aluminium toxicity is dependent on the degree of ionisation of Al present in the water (DWAF, 1996 B). “The median concentration of aluminium in river water is reported to be 0.24 mg/L with a range of 0.01 to 2.5 mg/L” (Bartram & Balance, 1996). Aluminium concentrations >1.5 mg/L can be lethal to trout (DWAF, 1996 B). The mean value of 0.233 ± 0.232 mg/L is well within the target range, whilst the maximum recorded reading of 1.014 mg/L is acceptable as well. The LSM value for non-fish farmed sites was 0.245 mg/L with a standard error of 0.014. The value for the farmed sites was 0.245 mg/L with a standard error of 0.014. Both values were the same, thus there is no statistically significant difference between Al ($p>0.05$) readings in fish farmed and non-fish farmed sites. Further, it was found that there is no statistically significant difference between surface and bottom concentrations of Al ($p>0.05$). There is a statistically significant difference between sites and this is due to the heterogeneity of sites.

r. Sulphate (SO_4)

Industrial wastes and effluent finding its way to water bodies may contain different levels of sulphate. “Sulphate also results from the breakdown of sulphur-containing organic compounds and is one of the least toxic anions and WHO does not recommend any guideline value for it in drinking water” (Bartram & Balance, 1996). Hydrogen sulphides are found in the sediment of dams where organic materials accumulate in anaerobic conditions. Sulphates are products of the biochemical oxidation of hydrogen sulphides and are also found in groundwater through natural deposits of magnesium sulphate, calcium sulphate or sodium sulphate (DWAF, 1996 B).

Concentrations above 250 mg/L can lead to health complications when consumed as drinking water (IDPH, 2012).The following levels of sulphates are expressed in mg/L: 0 - 250 is considered to be acceptable, 250 - 500 can be tolerated, 500 – 1000 is undesirable and >1000 the water is unsatisfactory for usage (DWAF, 1996 B). The maximum value of 86.390 mg/L found in the study sites is well within the target range. This also indicates a mean value of 8.081 ± 10.280 mg/L across the study sites for the WCP region.

The LSM value for non-fish farmed sites was 10.589 mg/L with a standard error of 0.668. The value for the farmed sites was 6.980 mg/L with a standard error of 0.387. There is a statistically significant difference between fish farmed and non-fish farmed for sulphate ($p<0.05$). The higher value for the non-fish farmed sites can be a result of microbiological activity during the decomposition of organic material in the sediment of the dam, where disturbances of the bottom layers were caused by incrementally turbulent conditions. This activity releases sulphates into the water column and can occur in the absence of fish farming. Higher organic loading can be due to intensive feeding practices as well as natural leaf and tree litter in the area finding its way to the reservoirs.

There is no statistically significant difference in the sulphate ($p>0.05$) concentration between surface and bottom readings. There is a statistically significant difference between sites ($p<0.05$) and it has been described in the K section. Further eutrophication can be caused by agricultural runoff and household and industrial effluent released in the receiving waters as well as other potential pollutants entering the system. It will always be difficult to isolate causes of pollution to receiving waters for the systems changes periodically according to climatic changes and activities in the area.

s. Alkalinity (mg $CaCO_3$/L)

Alkalinity is a measure of the presence of bicarbonate, carbonate or hydroxide constituents and provides a buffer capacity that prevents large variations in pH. Surface waters with low alkalinity (<75 mg/L) is subject to changes in pH due to dissolved gasses (Wurts, 2002). Total alkalinity concentration should not be lower than 20 mg/L in production ponds to maintain stable water chemistry. Pond pH can swing widely during the day, measuring from 6 to 10 at alkalinity concentrations < 75 mg/L. Large daily changes in pH can cause stress, poor growth and even death to fish “The recommended range for drinking water is 30 to 400 mg/L and high alkalinity (above 500 mg/L) is usually associated with high pH values, hardness and high rates of dissolved solids” (IDPH, 2012). Most aquatic organisms can live in a broad range of alkalinity concentrations and the desired level lies between 50-150 mg/L $CaCO_3$ (Wurts, 2002). At levels > 175 mg/L, the natural productivity of ponds decreases (DWAF, 1996 B). In areas where fish are farmed extensively, this could lead to lower production levels due to insufficient natural food being available. The maximum reading of 92.87 mg/L falls within the desired range for good fish production. The mean of 20.33 ± 20.60 mg/L is relatively low and creates unstable water chemistry conditions at those specific sites. Such low alkalinity concentrations also decrease the natural productivity of dams, and could lead to lower production levels where fish are farmed extensively.

The LSM value for non-fish farmed sites was 23.93 mg/L with a standard error of 2.81. The value for the farmed sites was 23.47 mg/L with a standard error of 1.29, thus there is no statistically significant difference between the alkalinity ($p>0.05$) at fish farmed and non-fish farmed sites. There is a statistically significant difference between the alkalinity readings ($p<0.05$) at the surface and bottom of the dam. This can be explained by the presence of CO_2 released from the sediment and bottom layers by the decomposition of organic material, and which affects the pH concentrations. Therefore alkalinity should be lower in the hypolymnion of dams due to acid complexes forming between CO_2 and heavy metals such as Fe, Mn, Cu adsorbed in the sediment (Wurts, 2002). The statistically significant difference between sites ($p<0.05$) is linked to the chemical composition of rocks and soils. High alkalinities are associated with most rock formation types, except for weathered sandstones. However, water bodies close to intensive agriculture may indicate a measurable phosphate-based alkalinity (DWAF, 1996 B).

t. Hardness (mg $CaCO_3$/L)

Water containing > 200 mg/L as $CaCO_3$ is considered to be hard and the following is a measure of hardness (expressed in mg/L as CaCo3) as described in DWAF (1996 B): Hardness of 0 – 50 is considered as soft water, a levels of 50 - 100 is moderately soft, 100 - 150 is slightly hard; 150 – 200 is moderately hard, 200 - 300 is hard and >300 is very hard. The maximum value of 98.07 mg/L is below the range for hard water (100-300 mg $CaCO_3$/L). The mean value of 26.85 ± 25.74 mg/L for all the sites is within the soft water range (0-100 mg $CaCO_3$/L).

Most aquatic species will grow adequately within a range between 30-100 mg/L. Aquaculture species exposed to $CaCO_3$ concentrations outside its upper and lower limits could have reduced growth, disruption of osmotic balance, decreased hatchability and survival of fry, and indicate lower resistance to disease (DWAF, 1996 B). “The more important aspect is the secondary effect water hardness can have on the other parameters, such as an increase in the toxicity of heavy metals” (DWAF, 1996 B).

The LSM value for non-fish farmed sites was 26.80 mg/L with a standard error of 1.15. The value for the farmed sites was 26.63 mg/L with a standard error of 1.80. This resulted is that there is no significant difference between the hardness concentration for fish farmed and non-fish farmed sites ($p<0.05$). The results also indicated that there was no statistically significant difference in hardness ($p>0.05$) between the surface and bottom of sites. The statistically significant difference between sites ($p<0.05$) can be ascribed to the surrounding geological formations. “Hardness of water is influenced by the geology of the catchment, in particular the presence of soluble calcium and magnesium inorganic constituents” (DWAF, 1996 B).

The concentration of physico-chemical parameters most likely not to be influenced by fish farming (depth, temperature, pH, TDS, Na, K, Ca, Mg, Fe, Cl, CO_3, HCO_3, Mn, B, Cu, Zn, Al, SO_4, alkalinity and hardness) indicated a strong affinity to regional site specific patterns and resulted in high level of heterogeneity among these locations. The process is mainly influenced by geology and the prevailing climate in terms of temperature and rainfall. Soils in the WCP are mainly from weathered Table Mountain Sandstones and shales from the Malmesbury Group. The Mediterranean climate of the WCP means that there is winter rainfall and subsequently diluted waters, whereas in summer higher temperatures cause increased evaporation and concentrated waters. Thus, major ions in the water fluctuate according to the changing weather patterns.

Overall, the water quality parameter ratios for fish farmed dams to non-fish farmed dams were ranging between 0.17 (SO_4) and 2.07 (Mn) (see Table 3.4). Most of the parameters have a ratio close to one indicating that the physical environment and site location have a much larger influence than the presence of fish on the concentration levels of these parameters. The ratio of carbonate was relatively high (71.24) and this can be explained by the presence of weakly buffered waters or it could be an outlier value. Furthermore, the influence of leaf litter from surrounding natural vegetation and soils accumulating through erosion and lateral transfers should also be considered as potential agents affecting water quality.

3.5.2 Parameters most likely to be influenced by the presence of aquaculture

a. Secchi disk

A Secchi disk is used to determine the transparency level in the water. The disc is lowered into the water and the depth at which the darker and lighter colours cannot be distinguished from each other is regarded as the transparency depth (Bartram & Balance, 1996). The recorded minimum reading of 10 cm is not good enough for optimal trout production. Trout requires a water transparency of >50 cm to feed optimally (Salie et al., 2008). Fish exhibit different levels of feed uptake when exposed to fluctuating turbidity levels (Hanson & Larsson, 2009). Such a low transparency reading could lead to a decline in FCR at fish farms (Salie et al., 2008). The maximum value of 510 cm is very good for trout production. It is accepted that the deeper the transparency, the deeper the depth of photosynthesis. A high level of photosynthesis with abundant plant life can lead to sustained fish production in the morning. The mean value of 139 ± 94 cm indicated that the dams involved in this research have sufficient transparency to support good feeding practices.

The LSM value for non-fish farmed sites was 116 cm with a standard error of 5. The value for the farmed sites was 147 cm with a standard error of 4. The non-fish farmed sites had a lower value for transparency over the research period. The Secchi disk reading is influenced by an increase in TSS concentration in the water and resulted in higher turbidity levels (Yi et al., 2003). TSS can be inorganic (sand, clay, silt) or organic (waste products, uneaten feed, phytoplankton). The inorganic TSS can be influenced by the transporting of soil particles from the adjacent landscape through erosion and runoff and considerable quantities can find its way to the water body (DWAF, 1996 B). The organic TSS is primarily influenced by the feed, faeces and organic effluent in suspension and secondarily through increase in phytoplankton biomass as a result of available nutrients. Available nutrients could be linked to fish farming operations as well as agricultural runoff and industrial effluent entering the water resource. Beveridge (1984) explains that “most studies on species culture have recorded increases in the levels of suspended solids and nutrients (alkalinity, total P, PO_4, NH_4-N, organic N & C) and decreases in O_2 in and around the enclosures and net cage systems”. Overall, both farmed and non-fish farmed sites were found to be appropriate for aquaculture, based on the Secchi disk reading. The maintenance of good visibility for the cultured species is crucial for optimum performance in the production system.

The Secchi disc reading is taken only in surface waters (usually within the first two meters) and therefore difference between surface and bottom is not applicable. There is a statistically significant difference in Secchi disk readings ($p<0.05$) at different sites and this can be related to the factors contributing to the Secchi disk reading namely fish metabolic waste and uneaten feeds, silt and sand due to erosion and plant debris from surrounding vegetation. There is a statistically significant difference between Secchi disk readings ($p<0.05$) at fish farmed and non-fish farmed. This difference can largely be attributed to the fish activity. Firstly, during fish farming operations water movement increases during feeding, creating turbulence that can dislodge settled solids from the cages and dam bottom and reduce the transparency of the water column. Secondly, with intensive farming, daily feeding is administered and the fish biomass produces metabolic waste that disperses and partially dissolves. The other contributing aspect is feed waste through uneaten feed and excess feed through insufficient management. Turbulent conditions also lead to the mixing of bottom and top layers resulting in an increase in total suspended solids. In holomictic dams the turnover phase can be associated with extreme fluctuations in the concentrations of the water quality parameters.

In non-fish farmed dams, transparency can be influenced by the presence of phytoplankton and other organic and inorganic debris brought to the dam by agricultural runoff and surrounding storm water outlets. Furthermore, the nutrient level in the water of specifically monomictic dams can also decrease the water visibility. Higher concentrations of phytosynthetic biomass usually lead to a decrease in transparency. “Under the same climatic conditions, autogenic (increase of biomass, decrease in light penetration and euphotic depth) and allogenic (use of the stored waters, anticipated breaking of the thermocline, increase of the mixing depth) processes may shift the structure of phytoplankton assemblage in the same direction even though the quantity of biomass remains linked to nutrient availability” (Naselli-Flores & Barone 2000). In some cases high phytoplankton biomass turns the water into a visual green peasoup appearance and concoction and the visibility can be further impaired.

b. Dissolved oxygen (DO)

The DO in reservoirs depends on the physical, chemical and biochemical activities in the water column. Measurements of DO provide a good indication of water quality and fluctuations of concentrations can be an early indication of changing conditions in the water body (Bartram & Balance, 1996). The DO concentration in dams is generally the limiting environmental parameter to stocking density and general performance of aquaculture species (Colt, 1986; DWAF, 1996 B). Many stocking densities are determined through calculating the oxygen budgets of dams. Every fish species has its oxygen requirement. In order to facilitate sustainable fish production, the dam has to deliver sufficient concentrations for optimal growth. It is advisable that there should be at least 5 mg/L of DO throughout the night and at dawn to support trout production (Salie et al., 2008). The biological oxygen demand will increase with fish farming and the dam has to be evaluated to make sure it can support additional demand for DO. The target water quality range for optimal growth and production of most aquatic species is 6-9 mg/L (DWAF, 1996 B). The minimum reading of 0.3 mg/L was way below the requirements and would not be supportive of fish farming (Klontz, 1991). Such a dam would have a weak biological balance (sufficient DO for aquatic plants and animals) and the ratio between producers and consumers of DO is disproportionate. Such low DO concentration could also be indicative of eutrophication and biological overload (DWAF, 1996 B). Fish would not be able to survive under such low concentrations and this value was probably taken during summer when there were no fish in the dam. In any event, such a dam is not a good site for fish farming for the fluctuation in DO is too great. The maximum value of 16.40 mg/L is excellent and borders on super-saturation of the dam. This can lead to gas bubble disease if not monitored carefully. The mean of 8.07 ± 2.49 mg/L for the dams involved in the research indicated that most of these dams have sufficient DO concentrations to support fish farming. The challenge is to maintain such levels and avoid any extreme fluctuations that can adversely affect the fish population.

The LSM value for non-fish farmed sites was 8.21 mg/L with a standard error of 0.1478. The value for the farmed sites was 8.09 mg/L with a standard error of 0.12. Although the concentration of DO is slightly higher for non-fish farmed sites, the difference of 1.2 mg/L indicates that the biological oxygen demand is almost similar in both. Thus, there is not a statistically significant difference between fish farmed and non-fish farmed dams with regard to dissolved oxygen ($p>0.05$). This finding is supported by Mirrasooli et al. (2012) who described that there was little difference between the upstream DO and the downstream DO from the discharge point of trout farms they investigated.

There is a statistically significant difference between the concentration of dissolved oxygen ($p<0.05$) at the surface and the bottom of dams. Farm dams generally have lower DO concentrations in the hypolymnion or bottom layers. Maleri (2011) reported that the duration of anoxia in the hypolymnia can be between 40 and 50 days. The bottom parts of the water column are characterized by the accumulation of organic and inorganic material which is brought about by alluvial processes in riverine ecosystems, agricultural runoff, housing developments and storm water conditions. The thermocline and the relationship between temperature/oxygen and depth in lakes are shown in Figure 3.7. External organic nutrient loading can be caused by fish farming and other agricultural and anthropogenic activities such as industry effluent, grazing cattle, spraying programmes with pesticides and fertilizers and household sewage (treated or untreated) discharge. Aquaculture operations usually attract bird populations, and bird excreta also add to the organic loading. The BOD of the dam increases as bacteria and fungi uses DO to decompose organic debris.

There is a statistically significant difference in dissolved oxygen ($p<0.05$) between sites. It is expected that the DO profiling for sites differ from one another. Each site has its own agents/vectors influencing the DO concentration. The DO levels can fluctuate in short periods of time within a single day or over longer periods of time due to sporadic weather pattern changes. The prevailing DO could be influenced by photosynthetic aquatic plant biomass, zooplankton, presence of pollution, organic loading and other sources of nutrient enrichment.

All these factors contribute to producing and using oxygen. A good site for fish farming should have stable concentration DO (≥ 5 mg/L) and should not fall below the minimum requirement for the species under production (Salie et al., 2008). Therefore, farmers are advised to calculate an oxygen budget and firstly determine the carrying capacity of a water body under prevailing stocking densities, then secondly, implement measures that ensure sustainability of fish biomass. It is considered good practice to always provided adequate DO concentrations conditions for low delivery to fish is a factor of exposed time, fish health and the water temperature (DWAF, 1996 B).

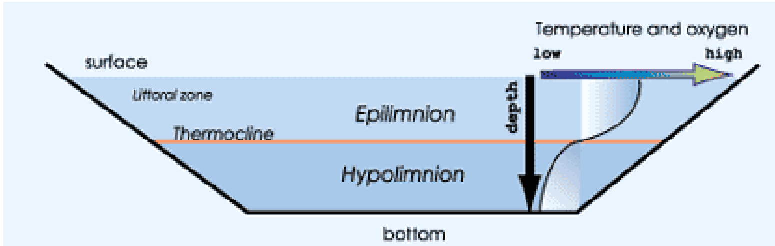

Figure 3.7. Thermocline and the relationship between temperature/oxygen and depth in lakes (Williams, 2001).

c. Phosphorous (P) and Orthophosphate (PO_4)

"Groundwaters rarely contain more than 0.1 mg/L phosphorus unless they have passed through soil containing phosphate or have been polluted by organic matter" (Bartram & Balance, 1996). Phosphorus compounds are present in fertilizers and pesticides as well as in waters with sewage, industrial wastes, storm water, agricultural runoff and fish farming effluent (DWAF, 1996 B). High P concentrations are also found where decomposition of organic material occurs (DWAF, 1996 B). The presence of high levels of P may produce a secondary problem in water bodies through stimulating algal productivity and enhancing eutrophication processes (Bartram & Balance, 1996).

The global target range, at which concentrations cause algal blooms, is ≤ 0.005 to 0.01 mg/L (Smith, 2003; Smith et al., 1999; C.E Boyd, personal communication, 10 August 2012). The minimum reading of 0.001 mg/L is below the global target range. Optimum growth of fish species is achieved at concentrations < 0.6 mg/L (DWAF, 1996 B). The maximum value of 0.735 mg/L is slightly outside the range for optimal growth, and can lead to changes in the trophic status of the water body. It is expected that no trophic changes will occur at levels ≤ 0.1 mg/L (DWAF, 1996 B). The mean value of 0.065 ± 0.233 mg/L is below the levels found by Heath (1990).

Increases in total surface phosphorous were found in dams with a trout production of approximately 5 tons per year (Maleri, 2011). Heath (1990) found P concentrations of 0.100 mg/L to 0.120 mg/L and a maximum concentration 0.420 mg/L in freshwater bodies with a stocking density of 1600 kg/ha of fish. "Fish farmers in South Africa calculated that generally 5-15 g of P is produced for each kilogram of dry pelleted feed fed to rainbow trout" (DWAF, 1996 B). The following calculation is relevant to the rainbow trout producers in the WCP:

<u>Box 1. Example of the amount of P released from feed into the environment for small-scale trout culture.</u>

In a dam approximately seven metres deep, with surface area of three hectares thus, (7 x 30000 m^2 = 210000 m^3), the following calculation applies: The trout farms visited during the research period indicated an average FCR of 1.3 feed to 1.0 kg fish weight. The extruded artificial diets used for fattening/on-growth of the trout included 7g of P per kg of feed, or 0.007. Thus, the result is 1.3 x 0.007 = 9.1 g P in feed. Further, one kilogram of fish x 0.0025 (2.5 g P in fish ÷ 6.6g P in water (65 % to sediment), thus 6.6 g P x 0.35 = 2.31 g P in water per kg trout produced (C.E Boyd, personal communication, 10 August 2012).

The LSM value for farmed sites was 0.101 mg/L with a standard error of 0.021. The value for the non-fish farmed sites was 0.049 mg/L with a standard error of 0.011. There is a statistically significant difference in phosphorous ($p<0.05$) concentration between fish farmed and non-fish farmed sites. Readings at farmed sites were almost double the P concentration compared with non-fish farmed sites. Maleri (2011) found that 84 % of the dams investigated showed an increase of > 50 % addition to the P concentration.

However, the LSM for orthophosphate for farmed sites was 0.185 mg/L with a standard error of 0.042. The value for the non-fish farmed sites was 0.168 mg/L with a standard error of 0.034. There was little difference in orthophosphate between farmed and non-fish farmed sites. "Orthophosphate is the reactive phosphorous and the most stable kind of phosphates in the water column of freshwater bodies. It is the limiting compound for micro-and macro plant growth. Phosphorus is essential for metabolism, and therefore present in animal waste" (Reddy et al., 1999). Phosphate levels should be interpreted in conjunction with the concentrations of nitrate, TSS and DO. Site-specific conditions should also be taken into account when determining P concentrations (DWAF, 1996 B). Maleri (2011) discussed this occurrence in detail in her study.

The statistically significant difference in P ($p<0.05$) between surface and bottom is due to the DO status of the hypolymnion. Sediments in dams can have high concentrations of Fe, Mn and P. These chemical compounds can be released to the water column in large quantities from the bottom of the lake when oxygen levels are very low. Therefore, the P concentration at the bottom and surface of dams will always differ due the P dynamics as in the P nutrient budget (DWAF, 1996 B, Maleri, 2011, C.E Boyd, personal communication, 10 August 2012; Zhang et al., 2012). The statistically significant difference of P ($p<0.05$) between sites is a result of different external and internal factors influencing the P concentration of sites. At all the research sites, farm dams are used for irrigation during the summer months. The farms were all located in the agricultural belt of the WCP. These sandy soils derived primarily from Cape Granite and Table Mountain Sandstone are low in nutrients, specifically low in phosphorous and are characteristic of the Cape Fynbos Biome (Mitchell et al., 1984; Cramer, 2010). Therefore, farmers use frequent dosages of fertilizers, such as double superphoshate and urea to enrich the soils for the farming of high-value plant crops such as grapes, deciduous fruit, olives, etc. However, the P concentration is low indicating that the perennial plants utilise the P effectively and the residual P has no negative impact on water quality. Therefore the major external point source of P to dams is from agricultural runoff. Other sources include effluent from industrial and housing developments. Phosphorous has been described as an important limiting factor for plant growth in dams (Temporetti & Pedrozo, 2000; Maleri, 2011; C.E Boyd, personal communication, 10 August 2012). Thus it is important to consider loading through other potential sources when investigating the impact of trout farming on the ecological balance of dams. The major sources of nutrients in lakes are indicated in Figure 3.8.

Most intensive fish farms are characterised by high stocking densities of candidate species and high volumes of artificial feeds. As previously explained, the potentially polluting sources can originate from the uneaten feeds, fish metabolic waste and non-removal of dead fish. Thus, P enters the water body via commercial fish feeds. The diets used for trout farming in the South Africa contain 0.7 g per kg of feed (L.F. De Wet, personal communication, 5 August 2012). It is estimated that 11 % of the total amount of P contained in fish feed dissolves in the water and that about 66 % of P in fish feed accumulates on the bottom sediments. The other 23 % is removed with the harvest (Smith, 1999; Temporetti & Pedrozo, 2000; Fried et al., 2012). Farm dams serve as P sinks and it is adsorbed to particles and settles in the substrate where it is gradually covered by sediment and remains there (Wang et al., 2012; Lalonde et al., 2013). This causes P to be removed from any further bio-circulation. Maleri's (2011) results indicate a concentration of 0.068 mg/L for non-production sites and 0.144 mg/L for fish production sites. Pulatsu et al., (2004) also found an increase in P values for fish farmed sites, but postulated that P in fish farming effluent can be much reduced if farmers comply with feed management guidelines. Therefore a holistic strategy is supported whereby the supply chain in fish feed manufacturing work together to follow guidelines which will provide future sustainability to the industry. This approach will also encourage environmental awareness and accentuate the potential negative effect it can cause.

d. Total Ammonia Nitrogen (TAN)

"In chemical analysis the TAN is measured and it includes two forms of ammonia: unionized form (NH_3) and the ammonium ion (NH_4^+) form, whilst the unionized form is considered to be toxic to fish" (Moogouei et al., 2010). In open water aquaculture such as the cage culture of trout, there is a likelihood of organic loading from metabolic wastes from cultured organisms and underutilized feeds. The accumulation can give rise to increased biological oxygen demand and the accumulation of toxic gases and the creation of anoxic areas under the cages (Tomasso, 2002; Beveridge, 2004; Pillay & Kutty, 2005). Ammonia is produced by the decomposition of nitrogenous organic matter through microbiological activity and is therefore present in surface and groundwaters. Higher concentrations are found in waters polluted by sewage, fertilizers, and agricultural and industrial wastes containing organic nitrogen, free ammonia or ammonium salts (Bartram & Balance, 1996). Certain mesophyllic aerobic bacteria such as *Nitrosomonas* and *Nitrobacter* spp convert toxic ammonia into nitrites and then into less harmful nitrates. "Nitrogen compounds, as nutrients for aquatic micro-organisms, may be partially responsible for the eutrophication of lakes and rivers" (Bartram & Balance, 1996). Ammonia can result from natural reduction processes under anaerobic conditions. The proportions of the two forms of ammonia nitrogen, i.e. free ammonia and ammonium ions, depend on the pH. The relationship between pH, ammonia and ammonium is illustrated in Table 3.6.

The target water quality range of 0.000 to 0.025 mg/L is expected to cause no harm to fish species (DWAF, 1996 B). Concentrations of > 0.3 mg/L can lead to adverse conditions for cold water fish such as rainbow trout, whereas concentrations > 1.0 mg/L are reported to cause mortalities to warm water fish such as the african catfish and common carp (DWAF, 1996 B). The maximum value of 6.480 mg/L can be detrimental to trout when maintained at low oxygen levels with a higher pH and temperature. The minimum reading of 0.015 mg/L is within the target water quality range. The mean value of 0.475 ± 0.682 mg/L is indicative across the sites that farm dams generally maintain higher than desirable levels. Fish farmers have to be aware of high TAN levels that might influence optimal production performance.

The LSM value for non-fish farmed sites was 0.593 mg/L with a standard error of 0.088. The value for the farmed sites was 0.476 mg/L with a standard error of 0.050. These values indicate that there is no statistically significant difference in TAN ($p>0.05$) between fish farmed and non-fish farmed sites. However, when comparing farmed and non-fish farmed sites Maleri (2011) reports an increase from 0.118 to 0.474 mg/L from non-fish farming to fish farming sites.

Table 3.6. Relationship between pH, ammonia and ammonium (Bartram & Balance, 1996).

pH	6	7	8	9	10	11
% NH_3	0	1	4	25	78	96
% NH_4	100	99	96	75	22	4

TAN concentrations in dams are usually caused by enriched effluent from agricultural runoff, storm water and surrounding housing settlements. Commercial agriculture contributes nutrients and other molecules to water ecosystems through fertilization and pesticides application regimes. The pathways of major sources of nutrients into lakes are shown in Figure 3.8. Through these regimes much N, P, K, etc eventually reach surface and bottom waters (Maharaj, 2005; Dabrowski et al., 2009).

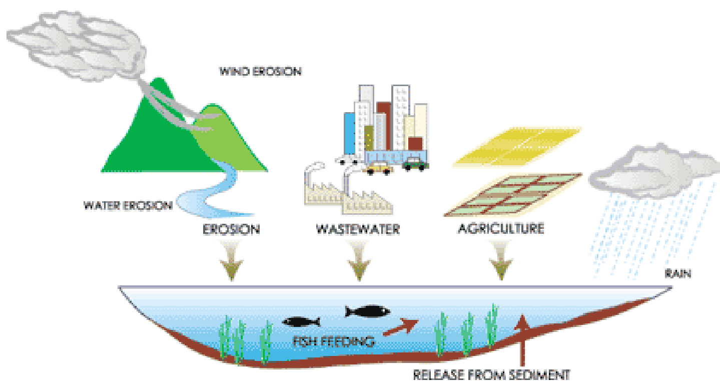

Figure 3.8. Major sources of nutrients in lakes (Williams, 2001).

There is a statistically significant difference in TAN ($p<0.05$) between surface and bottom waters due to accumulation of organic waste in the sediment. Thus, the higher TAN concentration in fish farmed sites can be ascribed to the addition of feeds and the presence of high density fish biomass. However, Maleri (2011) states that "more ammonia accumulates in the hypolimnion of production sites and that this can be directly linked to different processes in the sediment water interface of the dams and the consequent decomposition of organic material and corresponding deoxygenation". Thus, higher TAN concentrations in the bottom waters of dams are associated with the level of organic loading of dams, irrespective of whether the point source was fish farming or natural eutrophication through such plant and leave litter. Ammonium concentrations also tend to be elevated in waters where organic decomposition takes place under anaerobic conditions.

According to the South African water quality guidelines for agricultural use for aquaculture (DWAF, 1996 B), it is explained that "natural waters may also contain high concentrations of ammonium due to sewage effluent, effluents from industries and agricultural effluents (manure and fertilizers containing ammonium salts)". The results further indicate that there is no statistically significant difference in TAN ($p>0.05$) between sites.

e. Nitrate-Nitrogen (NO_3-N)

Nitrate accumulates in aquaculture production systems as the final product in the nitrification of ammonia through aerobic, mesophyllic bacteria (DWAF, 1996 B). "Other sources of nitrate are chemical fertilizers and pesticides from agricultural cultivated land as well as drainage from livestock housing and domestic and some industrial waters" (Bartram & Balance, 1996). Therefore it is omnipresent in slightly or highly polluted surface and ground waters. Unpolluted freshwaters usually contain only minute concentrations of nitrate at less than 5 mg/L (DWAF, 1996 B). The minimum reading of 0.009 mg/L is indicative of unpolluted water. The maximum value of 7.360 mg/L is indicative of some form of impact having occurred that enriched the water. The mean of 0.535 ± 0.851 mg/L was taken across the 29 sites involved in the research and shows that most farms (fish farmed or non-fish farmed) are within the range of impacted fresh water resources (< 5 mg/L). DWAF (1996 B) described that nitrate concentrations < 300 mg/L have no adverse effect on aquatic species. Therefore, although the maximum value reads high when compared to the mean, the concentration is considerably low for both agriculture and aquaculture requirements.

The LSM mean value for non-fish farmed sites was 0.493 mg/L with a standard error of 0.0726. The value for the fish farmed sites was 0.503 mg/L with a standard error of 0.0574. There is no statistically significant difference between fish farmed and non-fish farmed sites for Nitrate-Nitrogen ($p>0.05$. Further analysis also indicated that there is no statistically significant difference in Nitrate-Nitrogen concentration between surface and bottom waters and no statistically significant difference between sites for Nitrate-Nitrogen ($p>0.05$).

Nitrate is the least toxic to fish of the inorganic nitrogen compounds (DWAF, 1996 B). Aquatic plants utilise nitrate and it is assimilated into cell protein. Nitrate and ammonium are the most important nitrogen sources for phytoplankton growth especially when N availability is limited during summer (Domingues et al., 2011). Stimulation of plant growth through increased nitrate concentrations, especially of algae, may cause water quality problems associated with eutrophication. The subsequent die-off and decomposition of algae and other aquatic plants could produce secondary effects on water quality such as DO fluctuations and is undesirable to sustain fish production. In such events when the DO concentrations of the water will decrease, the production of CO_2 and NH_3 concentrations will increase and can further affect the pH balance.

Therefore it is important that future fish farming sites are selected with minimum existing aquatic plant growth for an increase in nutrients in the water column will result in escalating biomass. This will result in a rise in the BOD of the water body and can affect the fish negatively for DO concentrations will decline.

f. Nitrite-Nitrogen (NO_2-N)

"Nitrite is an unstable, intermediate stage in the nitrogen cycle and is formed in water either by the oxidation of ammonia or by the reduction of nitrate" (DWAF, 1996 B). During nitrification aerobic bacteria, mainly *Nitrosomonas* and *Nitrobacter* species oxidise ammonia to nitrite and nitrite to nitrate. Thus, oxidation and reduction can lead to cause rapid changes in the nitrite concentrations and in present in surface waters usually in low concentrations. However, higher level of nitrite may be found in treated sewage and industrial effluents (Bartram & Balance, 1996). No adverse effect on salmonid species is expected to occur in the range of 0 to 0.05 mg/L (DWAF, 1996 B). The minimum reading of 0.001 mg/L and the recorded mean of 0.024 ± 0.024 mg/L found at the sites involved in the research were both within the prescribed target range. However, it should be noted that the maximum reading of 0.200 mg/L is close to the value of 0.250 mg/L, which can be toxic to salmonids.

The LSM value for non-fish farmed sites was 0.017 mg/L with a standard error of 0.002. The value for the fish farmed sites was 0.023 mg/L with a standard error of 0.001 and it was found that there is a statistically significant difference in Nitrite-Nitrogen ($p<0.05$) between fish farmed and non-fish farmed sites. The difference in Nitrite-Nitrogen concentrations between fish farmed and non-fish farmed sites is likely to have a limited effect on the chemical composition of the water column. Maleri et al., (2008) also found the difference between Nitrite-Nitrogen concentrations to be negligible between fish farming and non-fish farming sites.

There is a statistically significant difference between surface and bottom concentrations of Nitrite-Nitrogen ($p<0.05$). Nitrite-Nitrogen is a product of nitrification by oxidative micro-organisms. Therefore with higher TAN concentrations in the bottom layers of dams, the Nitrite-Nitrogen should be higher as well if sufficient DO is available for nitrification. The results for DO have indicated a mean of 8.06 mg/L for all samples which suggests adequate DO availability for nitrification. There is a statistically significant difference between sites with regard to Nitrite-Nitrogen ($p<0.05$). This could be explained by the different periods of time during which the sites were exposed to agricultural activities, and different sources of effluent and discharge finding pathways to the dam.

g. Total suspended solids (TSS)

The recommended TSS level for sustained trout production is > 120 mg/L (Elsenberg, 2010). TSS can be of an organic or inorganic nature. Inorganic suspended solids can derive from sand and clay silting material from erosion and runoff while organic suspended solids derive from animal faeces and uneaten feed and dead fish. Higher levels can lead to physical irritation of the gills as well as providing a nutrient substrate for microbial growth. In open water dams the TSS has a direct effect on the penetration depth of sunlight, thus in cases where it is high, it can limit the photosynthesis depth. TSS is also indicative of the presence of the phytoplankton biomass. The maximum reading of 1396mg/L is in excessive of the recommended concentration and is unlikely to support trout farming. Such high values were reported by McLaughlin et al., (2009) for water bodies receiving effluent and discharges from construction sites. They noted values of 4130 up to 11 800 mg/L. Therefore, the maximum reading could have been recorded at a site with turbid water caused by erosion and runoff containing high concentrations of sand and clay particles. It could also indicate the presence of large carp populations which can lead to an increase in turbidity as a result of their feeding behaviour where they graze the bottom in search of food.

Du Plessis (2007) and Bruton (1985) both explain that the level of turbidity of inland waters is strongly affected by the amount of suspended material finding pathways into water bodies. During the selection of fish farmed sites, transparency is very important for optimal feeding and feed management. The mean value of 53.28 ± 114.4 mg/L is more acceptable for fish farming. Salmonid species indicate no adverse effects at concentrations of <86 mg/L (DWAF, 1996 B). It is indicated in Figure 3.9 that trout requires relatively clear vision to allow for efficient feeding.

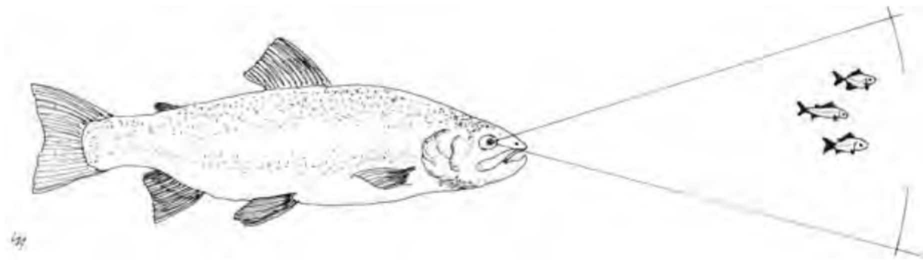

Figure 3.9. Clear vision will allow trout to feed efficiently (Woynarovich et al., 2011).

The LSM value for non-fish farmed sites was 23.76 mg/L with a standard error of 7.86. The value for the fish farmed sites was 55.94 mg/L with a standard error of 6.75. This indicated that there is a statistically significant difference in TSS ($p<0.05$) between fish farmed and non-fish farmed sites. The farmed sites have been shown to have a value almost twice as high as the non-fish farmed sites. Fish farming can increase TSS concentrations through waste, uneaten feeds, dead fish and increased fish movement during feeding and mating, and therefore farmed sites are expected to have higher TSS. However, Pulatsu et al. (2004) found the upstream TSS to be lower than the TSS downstream of the trout farm, but indicated that the difference was not statistically significant. Maleri (2011) indicated not much difference between the mean for fish farming sites (15.3 mg/L) and non-fish farming sites (14.2 mg/L).

There is no statistically significant difference in TSS ($p>0.05$) between surface and bottom sites, but a statistically significant difference in TSS ($p<0.05$) between sites. The TSS of individual sites can contain both organic and inorganic material. It is a function of the soil stability of the damwall and surrounding contours, the establishment of vegetation or the lack thereof, effluent discharges, agricultural runoff, and industry waste water used in housing developments and construction.

The concentrations of the following parameters (Secchi disk, DO, P, TAN, NO_3-N, NO_2-N, and TSS) are most likely to be influenced by fish farming. Firstly, the influence could be where organic particles emanating from excess feeds and faeces are suspended in the water column, changing the TSS concentration and consequently the water transparency observed in the Secchi disk reading. Secondarily, nitrogenous compounds are released into the water environment through nitrification by aerobic, autotrophic bacteria (*Nitrosomonas* and *Nitrobacter* species), as well as through denitrification. Dissolved oxygen levels are influenced by the rate of photosynthesis and decomposition of organic material. Phosphorous is mainly released from the feed. The ratio of water quality parameters of fish farmed to non-fish farmed sites ranges from 0.8 for TAN and 2.06 for P. These ratios are relatively low and are indicative of good water resource management by both fish- and crop farmers in the WCP.

The above-mentioned water quality parameters are directly associated with organic loading; either via fish farming practices or surrounding vegetation and agricultural activities. The total nutrient loading is relatively low and does not pose any significant threat to the sustainability of fish farming and irrigated crops. However, enriched waters can lead to algal blooms when the critical environmental cues (temperature, oxygen, air, pH, nutrients) are present. In such cases the quality of trout production can be compromised through off-flavours in the fish as well as the irrigation systems as a result of excessive clogging and consequent mechanical damages.

3.5.3. PCA Biplot analysis

A two-dimensional scatter plot was generated using the score for the first two principal components (Fig. 3.10). The first two principal components accounts for 40 and 17 % of the total variance respectively, and the two groups of fish farming and non-fish farming did not separate well based on the first two principal components. The fish farming component was mainly correlated with Fe, PO_4, TSS, Mn, Na and NO_2-N. whilst the non-fish farming component was correlated with Na, NO_2-N, Mg, Hardness, B and Ca.

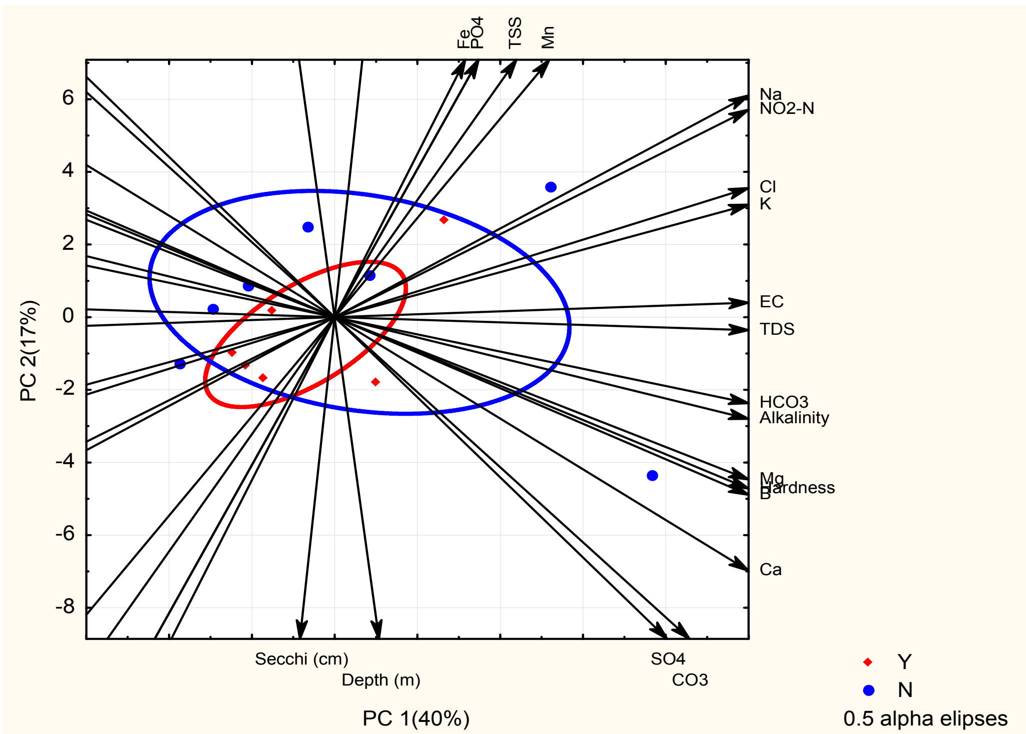

Figure 3.10. A two-dimensional scatterplot (PCA Biplot) of the average value for the water quality physico-chemical parameters recorded over 40 months at 29 sites. The Y (red) refers to fish farming and the N (blue) to non-fish farming samples.

3.5.4 Phytoplankton

a. Group Bacillariophyta (diatoms)

Twenty genera were identified in this group. Of the 2600 samples collected, it had a presence of 130 for the 29 sites over the five season research period (spring 2010 to spring 2011) and were absent from 2470 samples. The frequency of occurrence for the six groups across the 29 sites (in descending order) is shown in Table 3.7.

Table 3.8 described that the type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence of Bacillariophyta ($p>0.05$). Both genus and season has a statistical significance for frequency of occurrence for Bacillariophyta ($p<0.05$). The occurrence of phytoplankton is directly linked to the nutrient availability in the water. The nutrient concentration fluctuates according to season. In monomictic dams the nutrient levels are at their highest during the low water levels in summer and during mixing of the water in the turnover phase in winter. During winter nutrients are recycled from the enriched sediment of the dams and provide high concentrations of N and P to the water column. Increased N and P concentrations and consequently eutrophication have a direct influence on phytoplankton occurrence and can change the size distribution and community structure and diversity considerably (Du Plessis, 2007; Van Ginkel et al., 2007; Maleri, 2011). Du Plessis (2007) also states that in terms of biomass, the highest occurrence was found during the winter months. Trout farming is seasonal and the additional organic input from the farms can alter the trophic state of the water environment. In this study the fish farming season (April-October) coincided with winter when the dams are filled through rainfall and have turnover phases during periods of overflows. Therefore, if care is not taken to optimise feed management, farmers can experience secondary problems in water quality such as DO shortages due to an increase in algal populations. However, although high algal biomass affects DO it can also be beneficial to the primary production of reservoirs, specifically when utilize as a food source for herbivorous fish species.

In Figure 3.11 the phenomenon of seasonal development of phytoplankton occurrence is schematically presented. In summer production usually decreases and the production that does occur during summer is the result of regenerated nutrients. During autumn with the onset of winter weather conditions and increased turbulence and mixing, mainly by north-westerly winds, small blooms are generated. By June there are higher concentrations of nutrients due to turbulence and the mixing of water layers. The declining light levels limit production, which gradually falls off towards the winter rates.

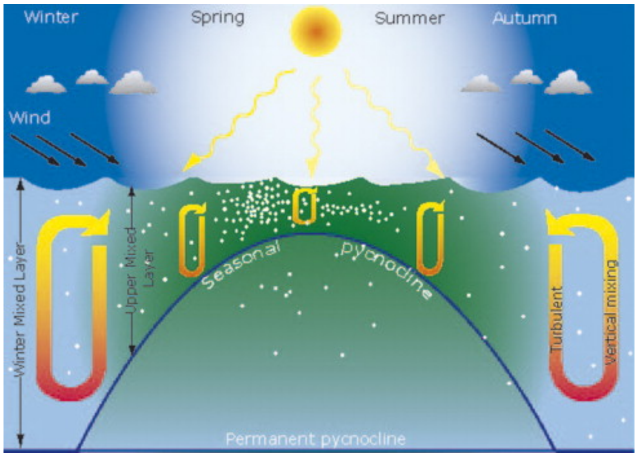

Figure 3.11. Schematic representation of the seasonal development of phytoplankton and the main physical factors affecting it. White dots represent phytoplankton biomass (Rey, 2004).

b. Group Chlorophyta (green algae)

Twenty-three genera were identified in this group. Of the 2985 samples collected, it had a presence of 371 and absence of 2614. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence of Chlorophyta ($p>0.05$). The results are presented in Table 3.8. Both genus and season had a statistical significance for frequency of occurrence of Chlorophyta ($p<0.05$). The statistical significance for genus and season has been explained in the section for the Group Bacillariophyta.

c. Group Chrysophyta (golden-brown algae)

Two genera were identified in this group. They were found to be present in 34 samples and absent in 226. The type 3 analysis of effect indicated that geographical location as well as season had no statistical significance for the frequency of occurrence of Chrysophyta ($p>0.05$). This can be seen in Table 3.8. Only genus had a statistical significance for frequency of occurrence of Chrysophyta ($p<0.05$). The statistical significance for genus has been explained in the section for the Group Bacillariophyta.

d. Group Cyanophyta (blue-green algae)

Five genera were identified in this group. They were found to be present in 66 samples and absent in 584. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence for Cyanophyta ($p>0.05$). This can be seen in Table 3.8. Both genus and season had a statistical significance for frequency of occurrence of Cyanophyta ($p<0.05$). The statistical significance for genus and season has been explained in the section for the Group Bacillariophyta.

e. Group Dinophyta (dinoflegellates)

Three genera were identified in this group. They were found to be present in 320 samples and absent in 70. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence for Dinophyta ($p>0.05$). This can be seen in Table 3.8. Both genus and season had a statistical significance for frequency of occurrence of Dinophyta ($p<0.05$). The statistical significance for genus and season has been explained in the section for the Group Bacillariophyta.

f. Group Euglenophyta (euglenoids)

Three genera were identified in this group. They were found to be present in 9 samples and absent in 381.The type 3 analysis of effect indicated that geographical location, genus and season had no statistical significance for the frequency of occurrence for Euglenophyta ($p>0.05$). This can be seen in Table 3.8.

Table 3.7. Frequency of occurrence of the six groups across the 29 sites (in descending order).

Group	**Total observations**	**Occurrence**	**Non-occurrence**
Chlorophyta	2985	371	2614
Bacillariophyta	2600	130	2470
Cyanophyta	650	66	584
Dinophyta	390	70	320
Euglenophyta	390	9	381
Chrysophyta	260	34	226

The Group Cryptophyta was omitted from the research for there was only one genus found in this group. The group is also known as the cryptomonads (Van Vuuren et al., 2006). The genera in the seven major groups of phytoplankton are listed in Appendix 6.

3.5.5 Production data

"The overall performance of fish in a system is affected by a number of factors including the environment and the condition of the fish itself" (Priestleyet al., 2006). The 15 trout producing projects all operated grow out facilities for juvenile fish (150-250 g) to market size fish of approximately 1.2 kg. The performance of the fish farming projects in terms of yields (total kg harvested) is dependent on the quality of juveniles supplied for stocking from respective hatcheries. There is a statistically significant difference ($p<0.05$) between source of juveniles and fish yield (kg of fish harvested). The juveniles were obtained from four different locations, namely from the hatcheries of Lourensford Trout Farm (Somerset West), Remhoogte Trout Project (Ceres), De Hoek Trout Farm (Gouda) and Jonkershoek Trout (Stellenbosch). The trout farms in the WCP area make use of more or less the same genetic stock of rainbow trout (*Oncorhynchus mykiss*) as well as the same formulated diet. The hatcheries which perform the best are the ones with the largest and healthiest stocking size juveniles (Salie, 2011). The one aspect that set hatcheries apart is the specific growth rate of the fish in each hatchery. Trout ova are hatched in winter (June/July) and placed in rearing systems during summer (Dec-Feb). The fish remain in the rearing systems until the juveniles are ready for stocking (April). Thus, maintaining good water quality (specifically during summer) provides a competitive advantage to hatcheries for most trout farming locations in the WCP experience water quality problems during this period. In warmer months the profiles of specifically temperature, adequate water flow rates and DO are important.

There is a statistically significant difference between FCR and amount (kg) of fish harvested ($p<0.05$). The FCR is an indication of the level of feed intake and utilization. Besides fish welfare, physiology and environmental conditions, the FCR of any fish production project is mainly a function of on-farm feed management (Goddard, 1996). Good feed management ensures less wastage and optimal utilisation of feed and reduces nutrient loading on the water environment (Pulatsu et al., 2004; Sørensen, 2012).

Table 3.8. The effect of variables genus, geographical location and season on the occurrence of the phytoplankton groups. The effects were considered statistically significant at a 95 % confidence level ($p<0.05$; ANOVA Wald F-statistics). The highlighted (light grey) rows indicate variables which had a significant effect on the occurrence of the different groups.

Group: Bacillariophyta		**Chi-square value**	**p-value**
	Genus	57.893	<0.0001
	Geographical	48.722	<0.0001
	Season	4.514	0.3409
Group Chlorophyta			
	Genus	194.375	<0.0001
	Geographical	39.092	<0.0001
	Season	9.776	0.044

Group: Chrysophyta			
	Genus	13.674	0.0002
	Geographical	0.303	0.860
	Season	1.555	0.817
Group: Cyanophyta			
	Genus	27.929	<0.0001
	Geographical	11.439	0.0033
	Season	10.152	0.0379
Group: Dinophyta			
	Genus	8.296	0.016
	Geographical	0.586	0.746
	Season	5.413	0.248
Group: Euglenophyta			
	Genus	0.446	0.8
	Geographical	11.606	0.003
	Season	2.135	0.711

The trout in the floating net cages are completely dependent on the quantity and quality of feed fed to them on a daily basis. The FCR's are calculated by determining how much average weight the fish has gained compared to the amount of feed used during that period. The farm average is approximately 1.3:1, thus for every 1.3 kg of feed used, the fish grows 1 kg (Salie et al., 2008). Sub-sampling of the fish population is conducted every month and the FCR calculated determines the adjustment of the daily required feed quantities. Projects with excellent FCR's usually deliver an increased final total kg of fish harvested.

The operational strategy of producing trout in net cages on irrigation dams in the WCP is limited to the few colder months of the year (Maleri et al., 2008). Therefore it is important that each project endeavors to reach the highest weight in the available months for optimum profitability of the operation. There is no statistically significant difference between physico-chemical parameters and kg fish harvested ($p>0.05$), thus it can be extrapolated that external factors such as feed management and quality of fingerling are more prominent than the water quality parameters of DO, pH, TAN, PO_4 and Secchi disk for trout production in irrigation reservoirs. These results are shown in Appendix 3.

3.6 Conclusion

In this chapter the focus was on evaluating the impact of rainbow trout aquaculture on the water quality of irrigation dams. It was determined that these dams were fit for the farming of high value trout destined for the higher income retail local and regional markets. The results from the WCP underline the importance of this region for the trout industry of South Africa (Maleri et al., 2008, Salie et al., 2008; Maleri, 2011; Salie, 2011; Stander et al., 2011). In order to provide sustainability to the aquaculture-agriculture integrated farming system, it is important that the wider understanding of the dynamics of such a system be explored. Whilst fish farming is dependent on the water quality, the commercial land-based crop farmer has to recognize the value aquaculture adds to the productivity of the water resource. Although irrigation systems using stored or diverted water have increased in number exponentially during the past 50 years, fish farming within these irrigated systems has not expanded equally (Fernando & Halwart, 2000). Therefore this situation, together with the agro-climatic conditions of the WCP, necessitates investigating opportunities in the field of aquaculture. Escalating pressure on access to clean and safe freshwater necessitates exploring ways to optimise existing use. Such initiatives should include the general populace of a country and has to provide tangible benefits in order to sustain it. Therefore to support the management of our freshwater resources and to achieve environmental goals, provision of clear economic benefits for fish farmers and the extended communities should be clear and comprehendible (SustainAqua, 2009).

Traditionally, water resource management endeavours to maintain water quality parameters within the *no adverse effect range*. This prescribed that water utilization activities should maintain the concentration of key parameters within targeted water quality ranges. These ranges have no known or anticipated adverse effect on the fitness-for-use of water and the protection of aquatic ecosystems (DWAF, 1996 B). However, the expectation is that any form of intensive agriculture, including aquaculture, is expected to have some level of environmental impact. For aquaculture to be profitable, the challenge is always to grow aquatic species as fast as possible within the shortest period of time, whilst taking cognisance of farming in balance with nature to ensure long term environmental sustainability (Cho & Bureau, 2001; Dinar et al., 2008).

Husbandry of rainbow trout in cages on irrigation dams recognizes that fish are kept under high stocking densities and fed volumes of high energy artificial diets rich in oils and crude proteins. The primary objective is to achieve accelerated growth. Waste production will always be a byproduct of aquaculture for it cannot be eliminated because aquatic species are unable to assimilate all the feed they consume and therefore part of the feed will remain uneaten. “Waste in aquaculture production systems can amount to an equivalent of one-third of the feed input” (Amirkolaie, 2011). Also, faeces are produced, adding to the waste output associated with unconsumed feeds. This is the nature of intensive aquaculture enterprises which are driven to maximise profits and optimise viability. However, the future success of the operation is threatened if farmers cannot foresee long term environmental sustainability and neglect managing water ecology within target water quality parameters.

The results indicated that DO, TAN and Nitrate-Nitrogen did not differ significantly between fish farmed and non-fish farmed sites. They further indicated that total suspended solids, Secchi disk reading, Nitrite-Nitrogen and phosphorus associated with fish farming, have been impacted and indicated increases in their respective concentrations. The fact that specifically DO and TAN indicated no significant increases associated with fish farming can possibly be explained by the stocking densities of trout at the projects. Although the density of fish were relatively high in the cages (3000 fish per 400 m^3), the stocking density in the reservoirs is low compared to the carrying capacity. Furthermore the nutrient loading emanating from the fish in the cages can potentially be neutralized by water replacement as a result of high influx from winter rains that fill up dams and cause overflows. Another factor that could lead to lower concentrations of dissolved and particulate compounds is the efficient removal through uptake by fauna and flora and in the case of TAN nitrification by aerobic autotrophic micro-organisms. This indicated the importance of aeration and mixing in dams to facilitate an ecological balanced system by providing uniform concentrations of DO at different depth levels in the water column.

Agriculture, when practiced incorrectly, has been globally recognized as an important non-point source contributor to pollution of water resources (Correll, 1998; Cullis et al., 2005; Rossouw & Görgens, 2005; Matthews et al., 2012). The role and function of aquaculture in a nutrient budget of irrigation reservoirs were emphasized and described. Reservoirs in the WCP are constructed in such a way that they are located at the bottom of slopes and contours so that water can easily flow into these water bodies through gravity. As a result enrichment via the application of fertilizers and pesticides to the crops and soils could lead to eutrophication if accumulated underutilized chemical compounds found their way to receiving waters. “Temporal patterns of nutrient concentrations in both soils and ground waters were mainly the result of fertilizer application” (Jovanovic et al., 2012; Van der Laan et al., 2012). All the irrigation dams in this research were surrounded by natural vegetation or perennial commercial plant crops such as vineyards, olives, deciduous fruit and citrus and therefore these planted soils are expected to produce less runoff. Plant crops can effectively utilize a large proportion of applied fertilisers and irrigation reservoirs surrounded by uncultivated soils are likely to produce more runoff with elevated concentrations of $N\text{-}NO_3$ and PO_4 resulting from fertilizer application. Therefore site selection for aquaculture should take cognisance of the surrounding land-use as well as other anthropogenic activities dams for the different ways in which the land is used could produce different volumes of runoff as well as different concentrations of mobilized nutrients.

The WCP has a Mediterranean climate with wet winters and dry summers. The first continuous rains are usually observed in May/June with the onset of winter. Agricultural nutrient loading is greater at the beginning of the wet winter months when the first mobilization and transport of soils starts via runoff. It is within this context that the impact of fish farming should be evaluated, and collaboration between the fish farmer and the land-based crop farmer is important to ensure both follow better management guidelines. For instance, Van der Laan et al. (2012) suggest that farmers can reduce N leaching from deeper soil profiles by not applying subsequent N fertilizer and forcing the crop to remove N from deeper in the soil profile. Complementary fish farmers can reduce organic pollution via wasted (unutilized) fish feeds by observing fish response to feed and adjusting feeding volume and frequency to fish behaviour. These practices could benefit the plant crop farmers through lower pollution levels of receiving waters and subsequently less clogging of irrigation systems. The fish farmer could benefit through savings on feed costs due to less wastage.

The analysis of variance between groups indicated that the difference in bottom and surface samples and the site location is more important than whether there was fish farmed or not. Burford et al. (2012) also found that total nitrogen and phosphorous were higher in bottom- than the surface layers. The difference in bottom and surface layers is directly linked to the ecological status of the sediment, which serves as a nutrient sink. In monomictic dams in the WCP, water mixes during the winter turnover phase and nutrients are released through upwelling of bottom waters brought about by torrential rains and wind turbulence. Thus, it was found that the organic state of the sediment and bottom waters is a function of the nutrient loading over time, irrespective of whether the point source was fish farming or past agricultural activity. Therefore, it is proposed that sediment analyses should be incorporated during the initial selection of sites in order to ensure good water quality to sustain trout farming. Initiating fish farming on a site with good physical and chemical water characteristics will increase the level of performance success (Maleri, 2008, Salie et al., 2008; Rosa et al., 2012). There are dams in the WCP bordering eutrophic status due to a history of collecting nutrient-rich effluent and runoff from different sources. When sites of this nature are used for fish farming, the nutrient status is directly influenced for fish farming will add to the nutrient budget. It is on the onus of the fish farmer to limit the nutrient addition through appropriate management.

Phytoplankton abundance is generally correlated with the availability of nutrients, specifically P and N. The occurrence and biomass distribution fluctuated with the season and available nutrient concentrations (Oberholster & Ashton, 2008; Bremner 2012; Van Ginkel, 2012). The dynamics of prevailing phytoplankton communities are important to fish farmers for two reasons. Firstly it can cause fluctuation in the dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis), and secondly it can cause algal taint of trout flesh due to geosmin producing species. Furthermore, the market discriminates against trout products with tainted flesh and off-flovours. Therefore, fluctuating oxygen levels as well as tainted flesh are detrimental to successful trout farming and should be avoided as far as possible. It is crucial for farmers to be able to anticipate when algal blooms are likely to occur in order to implement measures to avoid associated crisis management. One way of achieving this is to monitor the nutrient levels regularly and employ the required procedures when it is anticipated that the environmental conditions favour potential outbreaks. Such conditions could be high temperatures and adequate DO, rich organic matter and also high concentrations of CO_2 and NH_3.

The analysis of the production data indicated that water quality during the fish growing cycle has less of an influence on fish yield. Trout farming occurs during the winter months when the water quality is generally good with cooler temperatures and overflowing dams. The yields of farms were more associated with the quality of juveniles supplied by hatcheries and the FCR obtained. Through this analysis the importance of management to secure sustainable production was highlighted and initiatives are required to improve vocational skills of fish farmers.

The general water quality indicated that irrigation dam water quality is relatively well-managed by the commercial crop farmers in the WCP. Other provinces elsewhere in South Africa, i.e. KwaZulu Natal and Mpumalanga have been known to have dams with eutrophic and in certain cases hypertrophic statuses. Thus, the concern remains that our water resources as a whole in South Africa lack appropriate management and compliance to better management practices.

Irrigation dams in the WCP can play an important role in providing water bodies for aquaculture activities. Rainbow trout culture in floating net cage production systems has proven to be viable and it is envisaged that this province will be the nucleas of trout farming in South Africa for the future due to its favourable conditions of adequate water and a long enough cold season. Therefore, the opportunity presents itself to promote integrated aquaculture-agriculture farming systems in irrigation reservoirs. Through robust site selection, hands-on farm management and cooperation of farmers the initiative can be successfully exploited and contribute to sector growth. This will ensure wider participation to address socio-economic challenges in South Africa.

Aquaculture has proven to provide real benefits to rural and urban communities. Co-existence between fish farmers and crop farmers in an integrated aquaculture-agriculture system will only prosper when both primary and secondary users of irrigation dams apply practices to sustain good water quality. The challenge is to enhance the knowledge base at both levels.

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CHAPTER 4: Evaluating functioning of multi-used reservoirs in Stellenbosch area.

Abstract

The Western Cape province (WCP) has a Mediterranean climate with warm, dry summers and wet, cold winters. Commercial farmers of agricultural crops such as grapes, citrus, olives and deciduous fruit are dependent on summer irrigation to maintain quality production. However, excessive declines in water level of farm dams caused by withdrawal for irrigation could negatively impact aquaculture in multipurpose impoundments. Furthermore, aquaculture activities in such impoundments might increase plankton production and the planktonic particles could clog irrigation systems. Changes in water quality caused by aquaculture might also negatively impact on use of water for domestic purposes. This study described events associated with integrated aqua-agriculture systems and explored how small impoundments (300 000 to 1 500 000 m^3 in volume) mitigate these effects, increasing water supply in rural areas. Construction of small impoundments would convert land to aquatic habitats, but overall, the effort probably would increase local ecosystem complexity and be beneficial to biodiversity. The newly-established aquatic habitat would give rise to wetland and marshy areas and could improve and maintain ecological integrity of the lower reaches of the catchment. The study also placed aquaculture in perspective to wider nutrient loading on water resources via agriculture in pesticides and fertilizers.

4.1 Introduction

Supplying the global demand for sufficient water and food for the growing human population is a major issue, especially in Africa (Rosegrant et al., 2012). South Africa has an average annual rainfall of about 464 mm, compared with a world average of approximately 860 mm (Spinage, 2012). It is considered to be one of the 30 driest countries in the world. In order to provide enough freshwater to drink, grow food and for industrial use, governments build dams to store water (Molobela & Sinha, 2012). The WCP gets most of its rainfall in winter while the rest of the country is generally a summer-rainfall region. Semi-desert areas usually receive erratic rains which hinder their agricultural development. Due to limited water resources in South Africa, the pressure on authorities to supply sufficient quantities is mounting. The custodians of the countries water resources regularly face difficult decisions over water allocation rights. The challenge remains to provide equitable access, especially in years of drought (Dye, 2012). The traditional way of increasing water supply has been the construction of dams on major rivers to impound runoff (Gleick, 2004). South Africa has a well-established network of irrigation dams and canals on its major catchments to reserve water for future use. However, many impoundments had been built on smaller catchments to impound rainfall runoff. There are about 4000 dams in South Africa that are registered with the Department of Water Affairs' (DWA) dam safety authority. Other dams not owned by DWA were either municipal dams or privately owned (Pitman, 2011). Of the total number of dams in South Africa, there are more than 2000 small-scale farm dams in the WCP (Salie et al., 1998). Such small dams can provide water for agriculture, aquaculture, and other community uses such as recreation, and therefore would be beneficial in many countries, especially rural areas in Africa, where multiple-use reservoirs could be a valuable water supply (Boyd et al. 2010; Boyd & Salie, 2011).

In the region around Stellenbosch, South Africa, many small dams have been built to provide water for irrigation. In recent years rainbow trout (*Oncorhynchus mykiss*) has been successfully produced in cages in some of these reservoirs (Maleri et al. 2008; Salie et al. 2008; Salie 2011). Trout were mainly farmed during the colder winter months ranging from April to October (Maleri, 2008; Stander et al., 2011). There are investigations underway to explore the viability of tilapia (*Oreochromis mossambicus*) as a summer warmer species in the same dams for the remainder of the year when trout is not farmed (Rural Fisheries Programme, 2010). This area of fish culture as well as the farming system could provide a model for construction of multipurpose reservoirs in other regions of Africa.

The purpose of this study was to make an evaluation of multi-used reservoirs in the Stellenbosch region with respect to water storage and use, and water quality in dams with and without fish farming. Furthermore, it explored the effects of dams on catchment ecosystems dynamics with emphasis on species biodiversity, and to determine effects of current water use in these impoundments on other possible uses of the water.

4.2 Materials and methods

Description of dams and study areas

A number of farms were visited in and around Stellenbosch to assess and list its potential to conduct the research. Stellenbosch is situated in the Boland area of the WCP of South Africa. In Figure 4.1., the location of Stellenbosch in relation to Cape Town and the WCP is shown. Of the listed dams, three dams without fish farming and three dams with rainbow trout cage culture were commissioned. The decision to select these dams was based on farm owner cooperation and accessibility to do routine sampling. The selected six dams were located on five farms within a 40 km radius of Stellenbosch.

The region’s soils are derived and developed from a variety of geological materials from the Table Mountain group, Malmesbury group, Cape granite group and the Kalahari group (Fey, 2010). The oldest rocks were sedimentary formations of the Malmesbury group consisting of shales, schists, and greywacke (Theron et al. 1992; De Viliers, 2007). The Malmesbury sediments folded into chains of small mountains and were intruded by granite. The landscape eventually subsided and was covered by sands and shales. Erosion of the sands and shales exposed the remnants of the Table Mountain group and low granite hills and in front of these formations the coastal plain of the Western Cape developed (Theron et al., 1992; Fey, 2010). Farms for this study were on the slopes between the mountains and granite hills (Stellenbosch, Helderberg, Simonsberg, and Drakenstein Ranges) and the coastal plain. Soils on these slopes tend to be highly weathered, sandy, and acidic (pH 5-5.5), and they contain considerable quantities of stone (Conradie et al., 2002). Soils are of the Tukulu, Vilafontes, Avalon, Oakleaf, Glenrosa, Hutton, and Westleigh types (Soil Classification Working Group, 1991). Climate in the Western Cape region is classified as mild Mediterranean with mean monthly temperatures between 13 ^{o}C in September and 22 ^{o}C in February (Conradie et al., 2002), and rainfall measures up to about 1000 mm/yr (Stellenbosch Municipality, 2010).

The dominant natural vegetation type is known as Fynbos. Remnants of the Renosterveld vegetation type can also be observed in the area. Fynbos consists of evergreen, fine-leafed, thick, shrub-like plants, but much of this vegetation in the middle and lower reaches of catchments has been replaced with alien invasive species, *inter alia*, *Eucalyptus* spp, *Acacia* spp, *Pinus* spp, *Quercus* spp, *Populus* spp, fruit trees, pasture grasses, vineyards, and exotic weeds (Salie, 2003; Meek et al., 2010; Dye, 2012). Due to the perceived high water use by alien plants compared with native Fynbos vegetation, the South African government has initiated Working for Water programs to remove alien species from areas not devoted to agriculture and forestry and re-establish Fynbos vegetation on these tracts (Dye &Versfeld 2007; Van Wilgen, 2012). Ruwanza et al., (2012) reported that both complete clearing and thinning of alien invasive species promoted indigenous vegetation recovery and that a positive trajectory towards recovery of ecosystem structure and composition can be expected in future. Specific information on dams and catchments is provided in Table 4.1.

The irrigation dams were accommodating net cage culture of rainbow trout (Salie, et al., 2008; Gumbo, 2011). The estimated production of trout in 2010 was 6000 kg in Mountain Vineyards, 12000 kg in Patryskloof, and 18000 kg in Blue Gum. Trout fingerlings were stocked in April and fed three times daily with commercial diets. It was pelted feeds containing 38% crude protein and fed at approximately 2-3% of estimated body weight per day. Marketable-sized trout fish were harvested between October and December (Maleri et al., 2008; Salie, 2011). Harvested fish that were not processed immediately were gutted and blast frozen to be drawn and utilized at a later stage by the processing companies.

Figure 4.1. Map of Southern Africa indicating the location of Stellenbosch in relation to Cape Town and the Western Cape province (Courtesy of Trip-planner).

Water analyses

All the research sites had a designated sampling point to ensure uniformity of sampling areas. The point was permanently marked with a buoy. Sampling for water chemistry was conducted with a canoe between the shore and the buoy. Water samples were collected from the surface of the dam within the first meter at monthly intervals from January to August 2011. Samples were stored in transparent 350 mL plastic bottles and all the bottles were free of headspace. A combination of new and re-used bottles was used. Both type of bottles were thoroughly washed and rinsed with the particular dam's water to eliminated possibility of contamination with water from other research sites. The samples were immediately stored in a cooler container with temperatures of below -5 ^{o}C. The samples were delivered the same day or early the following morning to BEMLAB in nearby Somerset West (Lind, 1979; Wetzel & Likens, 2000). These samples were analyzed for pH, temperature, dissolved oxygen, electrical conductivity, total alkalinity, total hardness, total phosphorus, total ammonia nitrogen, nitrate-nitrogen, nitrite-nitrogen, iron, manganese, zinc, and copper (Eaton et al., 2005). The Secchi disk visibility was also measured on each sampling date.

Table 4.1. Description of dams used in study of water quality, hydrology, and catchments in Stellenbosch region of South Africa. The controls had no aquaculture, but trout were produced in cages in the dams listed under aquaculture.

Name ofdam	Farm	GPS coordinates	Area (ha)	Volume (m^3)	Average depth (m)	Shoreline (m)	Catchment plant cover
Controls							
Rooiland	Vergelegen	34° 4' 52.14" S 18° 54' 38.72" E	23.7	2 700 000	11.4	2240	Fynbos and vineyard
Normandie	Boschendal	33° 53' 12.97" S 18° 59' 5.77" E	11.8	720 000	6.1	1500	Fynbos and vineyard
Ashanti	Ashanti	33° 43' 35.425" S 19° 1' 52.21" E	14.3	1 170 000	8.2	2000	Vineyards and orchards
Aquaculture							
Blue Gum	Lourensfard	34° 1' 55.07" S 18° 55' 54.49" E	16.8	1 700 000	10.1	1980	Olive, fruit, eucalyptus, pine trees, and vineyard
Mountain Vineyards	Boschendal	33° 52' 24.88" S 18° 57' 20.43" E	8.0	675 000	8.4	1370	Fruit trees, vineyards, and pasture
Patryskloof	Cape Olive	33° 42' 26.19" S 19° 2' 1.23" E	7.0	280 000	4.0	1160	Olive trees

Hydrologic measurements

Historical data on air temperature, rainfall, and Class A pan evaporation in the area were available from Conradie et al. (2002). Data specifically for the study dams were either unavailable or incomplete. Catchment runoff was estimated by the water accounting method described by Yoo and Boyd (1994). The Thornthwaite method allowed calculation of monthly evapotranspiration rates needed in the water accounting method for estimating runoff (Thornthwaite & Mather 1957). Dam water levels were measured at weekly intervals from 19 January to 1 September 2011 with aid of a modified staff gauge. Research funds were inadequate to allow installation of water flow measuring devices for inflow of streams to dams, overflow from dams, and water removed from dams for use in irrigation. Dam capacities and areas at full-pool level were extrapolated from design drawings from original dam construction. Other general on-farm hydrological information was obtained during discussions with farm management and staff. This information gave a good perspective of stream flow dynamics in the drainage basin.

Catchment observations

The areas of catchments were delineated from satellite imagery, and the shoreline distances of dams were also obtained from these images. Catchment cover was assessed visually. Additional information on the catchment, including farming history, land use management practices, was also provided by the farm owner and manager. I also received information from other researchers and technical assistants who worked in the catchment area.

4.3 Results and discussion

Catchment and ecology

Only two of the farms, Vergelegen and Boschendal, had significant areas of native mountain Fynbos vegetation; the other catchments were devoted almost entirely to forestry and agriculture (Table 4.1). All farms had agricultural activities on dam catchments, and fertilizers and pesticides were routinely applied to crops. The common pesticides used and active ingredients in them are presented in Table 4.2. Dams were located in former agricultural land, and dam construction resulted in disruption of the areas around the dams creating open spaces for especially exotic plant encroachment. In some cases degraded areas through human disturbance and modification were typically invaded by alien species, especially weeds and shrubs (Chamier et al., 2012; Moran & Hoffman, 2012). The dam water levels decline greatly during the dry season exposing large areas of sparsely covered or bare soil. Due to the lack of moisture, these areas do not regenerate vegetation growth unless the moisture levels increase when dams are refilled by runoff during rainy months. However, dams in humid climates typically have wetland areas around edges and in upper ends where water inflow tends to be greatest and therefore the occurrence and spread of plant biomass follows the moisture regime (Chaney et al., 2012). Wetland areas have not developed around the edges of dams selected for this study due to erratic and fluctuating water levels during the dry season. Water is extracted for irrigation, starting from October and continues until May when the first rains usually arrive.

Table 4.2. List of pesticides used on farms that could possibly have entered waters.

Type	Product	Active ingredient
Fungicide	Kumulus	Sulphur
	Vivando	Metrafenone
	Cabrio	Strobulin
	Talendo	Penconazole
	Svitch	Fudioxinil ciprodinyl
	Topaz	Pencanozole
	Mancozeb	Dithiocarbamate
	Captab	Calcium polycarbophil
Insecticide	Proandub	Glyfosate
Herbicide	Gramoxone (preglove)	Paraquat dichloride
	Fuzilade	Flazifop-p-butyl
	Aromasin	Exemestane

However, it was visually observed that wetland vegetation has developed in small water courses that conveyed water into dams and received dam overflow during the wet season. These areas ranged in size from 1000 m^2 to about 5000 m^2 in the inflow and outflow zones of each dam. Water sources for the dams were: direct rainfall, agricultural runoff, sheet flow runoff from catchments, groundwater seepage during the wettest periods and inflow of ephemeral/intermittent streams (Butler, 2001; De Groeve, 2003). Inflowing streams had diversion structures that conveyed a portion of their flow away from dams and into the natural watercourse to maintain downstream flow. The provision of base flow during the year enabled these tributaries to sustain their ecology.

A number of indigenous wetland and riparian plant species were observed in the inflow and outflow areas and included *Aponogeton distachyos*, *Typha capensis*, *Scirpus* sp., *Pteridiumaquilinum.*, *Ischyrolepis*sp, *Restio* sp.; *Cliffortia* sp., *Pentaschistis malouinensis*, *Halleria lucida*, *Merxmuellera cincta*, and *Epischoenus gracilis*. The presence of cosmopolitan species such as *Zantedeschia aethiopica* and *Phragmites australis* were also recorded. Alien invasive species observed in the wetland areas included *Acacia* spp, *Hakea sericea*, *Myriophyllum spicatum* and *Arundo donax*. These listed alien invasive plants were priortised in numerous plant control projects to manage the ecology of wetlands (Forsyth et al., 2012). However, these plant communities created habitat for amphibians, reptiles and small birds. The open water areas of the dams created favourable habitat for birds. Herons, kingfishers, Egyptian geese, fish eagles and cormorants were observed in and around the dams. Frogs were seen in the dams, and deer, baboons, and several species of small mammals were observed drinking water from the dams. The dams also contained fish that have been stocked purposely (in addition to those used in aquaculture cages) or entered naturally via connecting canal systems and tributaries. The fish included mullet, bass, bluegill, carp, tilapia, catfish, and brown and rainbow trout. These observations most likely suggest that the dams have increased the amount of aquatic habitat and enhanced biodiversity in the study area. In addition, they provide irrigation water critically needed for crops and allow the possibility for commercial aquaculture. The dams also could supply water for livestock, domestic use and recreation if required by the farming community.

Water balance

None of the dams had water pumped into them from other dams or streams during the study. However, it is not uncommon at some dams in the area for farmers to pump water from streams into dams to supplement water entering from catchments. During the study there was no feasible way to estimate the quantity of water diverted from dams to support downstream flow. Thus, it was impossible to obtain sufficient data for making detailed water budgets for the dams. The water balance was estimated for a hypothetical, 1 ha catchment units and 1 ha dam units for conditions existing in the Stellenbosch region.

Net seepage from dams in the area was estimated to be 190 mm/month (De Groeve, 2003). These data allowed an estimation of the water balance (excluding runoff into dams) for a 1-ha area of dam surface. Inflow by rainfall would average 6910 m^3/ha/yr, but outflow through seepage and evaporation would be 35230 m^3/ha. Thus, the water balance is -28320 m^3/ha. The water for replacing seepage and evaporation losses and maintaining dam volume must be provided by runoff from dam catchments.

The average moisture holding capacity of soils in the study area was reported to be about 125 mm/m of soil depth and the plant root zone extends to roughly 1 m in the soil (Conradie et al., 2002). This information allowed runoff to be estimated by the moisture accounting method (Table 4.3). Runoff will occur in June, July, August, and September, and the average annual runoff should be about 153 mm (about 22% of annual rainfall) or 1530 m^3/ha/yr. Thus, 18.5 ha of catchment would be necessary to provide enough runoff to compensate for the excess of seepage plus evaporation over direct rainfall into dams. An additional 6.5 ha of catchment would be needed for each 1 m depth of storage volume over 1 ha of dam surface area. Thus, a 10 m deep dam would require a catchment area of 83.5 ha per hectare of water surface area. Calculations above assume that the entire catchment of dams were located on the slopes of the granite mountains at the upper ends of the catchment. However, a portion of all catchments was located on the mountains, but the area of the catchment that consisted of granite outcrops could not be estimated from the maps and satellite images available. The surrounding granite hillslopes do not retain moisture for long periods and holding capacity of these granite outcrop areas is essentially zero (Jumbi et al., 2012). The runoff estimations should be adjusted for these areas, because almost all of the rain falling on rock outcrops would be converted to runoff. To illustrate the problem with runoff estimates, Patryskloof Dam at Cape Olive Farm is 4 m average depth and has a catchment area of 530 ha. Based on the runoff estimate (Table 4.3), this dam would need 132.5 ha of catchment area, and it has 530 ha. This dam has plenty of catchment areas available to fill it to capacity in a normal year. However, Ashanti Dam at Ashanti Farm would need 1707 ha of catchment to fill on a normal year, and the catchment area provided by the farm manager is only 320 ha. Nevertheless, this dam fills with water and the possibility that water is pumped to complement dam levels is also possible. More reliable data need to be obtained on catchment areas and soils in order to assess runoff more accurately.

Water levels

Water levels decreased steadily during the period January to May. However, water levels began to increase in June in response to greater rainfall, lower evaporation rates, and the termination of water extaction for irrigation during the winter. By September, water levels were near the levels observed in January. In Table 4.4 water levels for the different dams are indicated.

Water quality

Water quality data are summarized in Table 4.5. Although there were no large differences among dams within the control group and the aquaculture group or between the two groups, there was a tendency of greater ammonia and nitrate concentrations in the dams with aquaculture (Cai et al., 2012). This is not surprising considering that feeds were applied to the cages. Earlier studies are in agreement and suggested that feed inputs also lead to greater phytoplankton productivity (Maleri et al. 2008; Maleri, 2011). It has been suggested that increased phytoplankton production in dams as a result of aquaculture could result in clogging of irrigation systems (Koegelenberg et al., 2002; Du Plessis 2007). Therefore careful management of nutrient levels is important to limit maintenance on irrigation systems.

The water quality in the dams was also suitable for livestock watering and many other domestic uses. For use in households, the water probably would need to be clarified by alum treatment and boiled or treated with chlorine to assure a sanitary condition. It has been reported that constructed wetlands are among the oldest forms of efficient technologies for the improvement of water quality of river and dam water for drinking purposes (Kurzbaum et al., 2012). Many of these dams are also used for recreation and no health implications were reported at the time of the farm visits. In the communities where it was observed that children were using the dam for fishing and swimming, the farm management was alerted to the importance of following water safety regulations to prevent calamities.

4.4 Conclusion

In general commercial land-based crop farmers could not provide accurate data on water extraction. It was evident that water was extracted according to demand and on an *ad hoc* basis. There was a lack of definite irrigation regime, especially during very warm summer months. Most farmers were attentive on maintaining sufficient water levels to prevent shortages. Although it was impossible to derive a detailed water budget for each dam because of the lack of accurate information on water withdrawal and diversion from dam for irrigation and downstream flow, the study revealed that these multipurpose dams had drastic declines in water level as a result of water use for irrigation. Some dams were also observd to be almost completely dry in summer. Rainbow trout cage culture has been possible because water levels remained fairly high during the cooler part of the year. However, if such dams were located in warmer climates, they might not be suitable for aquaculture because of poor water quality and crowding of fish when water levels are low. On the contrary, net cage culture would be possible during colder or warmer periods if sufficient water levels can be maintained to allow free space for lateral flow under the cages. The challenge is to motivate farmers to manage water extraction in such a way that there remains enough water in the dam during peak irrigation. If this objective can be achieved, it could provide a year-round farming system with warm- and cold water species. Species such as tilapia and catfish can be farmed complimentary to trout on a rotational production strategy.

The dams resulted in conversion of land to water surface and creating micro-habitats in and around the storage system. In the semi-arid climate of South Africa, the formation of permanent water surfaces and pockets of wetlands and marshes associated with the dams, led to enhancing an ecosystem complexity with increasing biodiversity. These micro-habitats established animal and plant life and enhanced the ecosystem functioning. Furthermore, wetland areas can be significant in reducing water pollution caused by effluent and discharges from surrounding human settlements and industries. Therefore ways of establishing wetlands should be encouraged as biological filtration systems and to maintain the health of our catchments.

The primary purpose of dams in this study is for irrigation. Enrichment of the water resource via nutrients from aquaculture would possibly enhance the value for crop irrigation. Generally soils in the WCP are nutrient-poor and farmers fertilize to increase micro- and macro nutrient concentrations. The use of aquaculture effluent for irrigation could result in savings to the commercial crop farmers. It is actually crucial that especially N and P concentrations in effluent are quantified to manage nutrient balance in soil. However, it has also been recorded that increased phytoplankton production in dams as a result of aquaculture could result in clogging of irrigation systems. Therefore, nutrient loading via aquaculture should be closely monitored with the onset of summer irrigation until the first rains arrive in May/June. Aside from possibly clogging irrigation systems, eutrophication of dams is likely not to be of major concern in the agricultural community of the Stellenbosch and surrounding area. The water quality results overall indicated that the commercial crop farmers were managing the water resource quite well and eutrophication was not wide-spread. In other areas where dam water would be used for domestic purposes in addition to irrigation, eutrophication would possibly be of other concerns such as excessive turbidity, undesirable colour, and taste and odour problems. However, in cases where this situation occurred, the affect was acute and the water quality returned to acceptable levels within a few days.

The network of irrigation dams in the WCP sustains a successful agricultural industry. Although its primary purpose is irrigation of plant crops during dry warmer months, it provides a valuable water source to the rural communities. However, construction of such dams would cause changes in land use, such as the relationship of terrestrial habitat to water surfaces where arable land would be replaced by water storage bodies. Opportunities associated with access to water would further change the migration patterns of rural dwellers as they strive to exploit initiatives linked to the availability of water. Nevertheless, the inclusion of areas in the landscape at the interface of terrestrial to water surfaces would have a beneficial effect on local ecosystems. The challenge is to find the ecological balance to sustain the active ecosystems. However, such projects would be hydrologically complex, and much more research is needed for development of guidelines for dam site selection, design, construction, and operation. The acquiring of relevant information would be beneficial to incorporating aquaculture as a viable farming system in our catchments.

Table 4.3. Estimation of runoff by the soil moisture accounting method.

	Month											
Variable (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Soil moisture at beginning month	0	0	0	41	125	125	125	125	105	77	8	0
Rain during month	16	48	88	140	95	96	60	42	45	31	18	12
Total available moisture for month	16	48	88	181	220	221	185	167	150	108	36	12
Potential evapotranspiration during month	82	63	47	36	34	44	40	62	73	100	102	102
Soil moisture remaining at end of month	0	0	41	145	186	177	145	105	77	8	0	0
Soil moisture holding capacity of soil	125	125	125	125	125	125	125	125	125	125	125	125
Runoff during month	0	0	0	20	61	52	20	0	0	0	0	0

Table 4.4. Water quality data for dams with cage culture and without cage culture.

	Cages				Controls		
	Mountain	Cape	Blue		Normandi	Ashanti	Rooiland
Variable	Vineyards	Olive	Gum		*	*	*
Temperature (^{o}C)	19.8 ± 3.4	18.6 ± 2.6	20.9 ± 4.5		20.4 ± 2.6	20.3 ± 2.7	20.8 ± 2.5
Dissolved oxygen (mg/L)	8.25 ± 0.67	8.54 ± 0.91	9.26 ± 1.11		7.93 ± 0.52	8.68 ± 0.64	*
pH	7.09 ± 0.36	7.22 ± 0.32	7.40 ± 0.06		7.00 ± 0.20	7.57 ± 0.37	7.27 ± 0.20
Secchi disk (cm)	124 ± 59	58 ± 36	147 ± 90		144 ± 168	96 ± 49	57 ± 27
Conductivity (mS/m)	7.28 ± 0.79	8.81 ± 1.20	5.70 ± 1.18		4.33 ± 0.72	13.16 ± 0.94	15.14 ± 1.78
Total alkalinity (mg/L)	12.5 ± 2.7	8.4 ± 0.8	6.1 ± 1.6		4.1 ± 0.7	18.8 ± 1.6	14.1 ± 0.8
Total hardness (mg/L)	16.1 ± 2.4	17.7 ± 6.2	15.9 ± 3.2		12.5 ± 2.9	25.4 ± 4.6	17.7 ± 3.5
Phosphorus (mg/L)	0.018 ± 0.025	0.018 ± 0.021	0.028 ± 0.038		0.014 ± 0.018	0.042 ± 0.045	0.015 ± 0.020
Total ammonia N (mg/L)	0.33 ± 0.16	0.31 ± 0.13	0.56 ± 0.38		0.19 ± 0.08	0.40 ± 0.16	0.27 ± 0.12
Nitrate N (mg/L)	0.75 ± 0.76	0.15 ± 0.20	0.18 ± 0.19		0.13 ± 0.11	0.40 ± 0.43	0.22 ± 0.15
Nitrite N (mg/L)	0.014 ± 0.006	0.021 ± 0.007	*		0.023 ± 0.017	0.030 ± 0.020	*
Iron (mg/L)	0.079 ± 0.042	0.387 ± 0.105	0.463 ± 0.451		0.296 ± 0.384	0.537 ± 0.594	0.540 ± 0.220
Manganese (mg/L)	0.001 ± 0.002	0.002 ± 0.002	0.016 ± 0.019		0.020 ± 0.020	0.082 ± 0.120	0.010 ± 0.011
Copper (mg/L	0.003 ± 0.003	0.002 ± 0.002	0.001 ± 0.001		0.006 ± 0.007	0.002 ± 0.003	0.003 ± 0.005
Zinc (mg/L)	0.005 ± 0.004	0.006 ± 0.003	0.009 ± 0.003		0.010 ± 0.003	0.012 ± 0.006	0.004 ± 0.003

* empty blocks indicate missing data

Table 4.5. Water levels recorded at the different dams. Each dam was staked with a zero point marker on 18 January 2011. The levels were read on a weekly basis thereafter. The negative readings indicated an incline of the level compared with the previous week's reading.

Date	Commercial farms					
	Bluegum	Rooiland	Cape Olive	Ashanti	Mountainvines	Normandi
2011/01/18	0	0	0	0	0	0
2011/01/25	79	25	21.1	58	40	91.2
2011/02/01	83	41	109	57	37	91.5
2011/02/08	84	23	16	42	33	-2
2011/02/15	42	40	28	49.5	30	81
2011/02/22	157	99	26	46.5	42	114
2011/03/01	103	47	21	50	23	81
2011/03/08	47	132	80	48	23	79
2011/03/15	35	98	21	60	32	109
2011/03/22	137	45	22	*	80	30
2011/03/29	132	47	16	42	33	-2
2011/04/05	190	40.05	15	30	41	11
2011/04/12	160	51	32	60	35	*
2011/04/19	150	27	-20	-8	35	3.2
2011/04/26	-140	32	15	41	20	-67
2011/05/02	200	47	0	-29	2	-35
2011/05/09	-100	4.5	0	-29	2	0
2011/05/16	-100	-16	0	-19	2.5	4
2011/05/23	0	-16	-26	-44	-7	-16
2011/05/31	-525	-44	-28.7	-52	-13	-42.1
2011/06/07	45	-36	0	-22	-22	-38
2011/06/14	-150	-33	0	-28	-33	-12
2011/06/21	-150	-48	-50	-54	-48	*
2011/06/28	-447	-52	-35	-40	-70	-100
2011/07/05	-180	-105	*	-74	-64	-124
2011/07/12	5	-79	-15	-80	-30	-42
2011/07/19	-60	-45.5	-19	-58	-10	-28
2011/07/26	-210	-50	0	-38	-5	10
2011/08/02	30	-30	-40	-35	-25	6
2011/08/09	-170	-65	15	-30	-16	-30
2011/08/16	-110	-50	0	-30	-25	-45
2011/08/23	-100	-35	-24	-25	-50	0
2011/08/30	-60	-15	-20	-27	-20	-50

* empty blocks indicate missing data

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CHAPTER 5: Mitigation to reduce organic pollution emanating from excess feeds and fish metabolic wastes

Abstract

Farm effluent from aquaculture contributes to pollution of water resources. Although fish farming effluent can contain a number of organic and inorganic pollutants from feed and faeces, it contains two key nutrients that are essential for life in freshwater ecosystems are phosphorus and nitrogen compounds. The increase of N and P could fuel eutrophication in reservoir ecosystems, reducing biodiversity and the ecosystem's resilience to future additional anthropogenic stress. Mitigation should be directed firstly at reducing loading through improved feed and feeding management and secondly through extracting and removal of suspended and dissolved substances. A waste reduction strategy, including feed quality, self-feeders and floating gardens, is proposed. Incorporating similar measures would be necessary to maintain sustainable aquaculture growth in to the future. Mitigation should be addressed at reducing nutrient loading irrespective whether the source is aquaculture or not and therefore any reduction in nutrient loading would add to maintaining environmental integrity.

5.1 Introduction

Fish farmers are continually faced with challenges regarding environmental sustainability and the safety of their products (Buzby, 2001; Jahncke, 2007). The term sustainable development simply implies that current demands on resources will not affect the ability of future generations to meet their demands and any food production system need to be efficient and as far as possible cause minimal impact on the environment (WCED, 1987; Colt et al., 2008; Snow & Ghaly, 2008). Aquaculture is no different from any other form of agriculture and both sectors have to consider the ecological, social, and economic aspects of development (White et al., 2004). Therefore, to fully understand the concept, farmers' reactions to these challenges are based on their understanding and comprehension. They need to understand in which way their activities impact on the environment and to what extent the envisaged impact will infringe on the profitability of their operations. The success of their economies of scale and relative size of their fish farms have no direct association with the compliance of farmers to reducing waste output (Gumbo 2011). In past times aquaculture was traditionally a component of a mixed farming system conducted in association with other land-based animals such as large stock and ducks. Such farming systems were either managed extensively or semi-intensively and were aimed at meeting subsistence and local market needs (Beveridge & Little, 2002). In this particular farming system, no artificial feeds were used and fish were generally fed on products in the natural food pyramid as well as byproducts from agriculture and other food producing industries (Azim & Little, 2006). Therefore traditional aquaculture was sustainable as long as the natural food pyramid was maintained. However, today aquaculture has progressed to market-driven demands for seafood products making extensive farming impracticable and unprofitable to deliver to these markets (Lansdell, 2010). Intensive culture of fish relies on aquafeed as their primary source of nutrition. In intensive aquaculture, commercial feeds can contribute 30-60 % to operational costs (Sugiura et al., 2005; Gurung et al., 2006). It is expected that wastes produced by fish farms will collect on the bottom of the water body. Methods use to contain and collect wastes, both solid and dissolved, is very costly and difficult to operate (Cho & Bureau, 2002). Therefore, it is imperative that sufficient attention should be paid to reduce waste output to the environment through cost-effective methods, and also maintain with ease of operation (Cho & Bureau, 2002; SASSI, 2011; WWF, 2011; Webb, 2012).

According to the National Water Resource Strategy (DWAF, 2004), South Africa depends mainly on surface water resources for most of its urban, industrial and irrigation requirements. It is postulated that agricultural practices can have a significantly impact on South Africa's water resources with regard to availability and quality. Furthermore, the distribution of natural vegetation is also associated with the moisture regime according to the abundance and location of water resources (Moran & Hoffman, 2012; Struyf et al., 2012). With the general application of pesticides and fertilizers in commercial agriculture, it is expected that there would be an increase in the amount that washes and leaches into the groundwater. "Freshwater pollution, in the form of chemical oxygen demand, is estimated to be 4.74 tons/km^{-3} while the average phosphorous concentration in the natural water resources of South Africa (as orthophosphate) has been estimated at 0.73 mg/L. These values are indicative of moderate to highly eutrophic conditions in South Africa's freshwater resources" (Oberholster & Ashton, 2008). While water enrichment in open water aquaculture systems can be partially attributed to agricultural runoff and the decomposition of organic materials in the pond and surrounding catchment, the main source of nutrient enrichment is often via unutilized feed and fish excrement. It is accepted that commercial intensive aquaculture activities would produce effluent which contains significant amounts of dissolved organic matter and nutrients, and could contribute to enrichment of the water column (Axler et al., 1997; Deksissa et al., 2003; Snow & Ghaly, 2008). The main components of these wastes are considered to be phosphorus- and nitrogen-based metabolites that are not effectively used by the fish. Milne (2012) described that in a sensitivity analysis of a lake with trout cage culture the non-point sources are the most significant parameter for total phosphorous loading, followed by the lake sedimentation, then the contribution by aquaculture. This put in perspective the relative contribution of aquaculture to the nutrient budget of water bodies. Phosphorus is the limiting nutrient in freshwater primary production, and excessive levels can cause premature eutrophication and the deterioration of water quality (Coloso et al., 2003; Schultz et al., 2003; McDaniel et al., 2005). Thus, it is important to treat the water before it is released back into the environment as it can have a detrimental effect on the ecology of the water body and lead to irreversible changes in the ecosystem.

The implementation of plant-based filtration systems is a simple solution to reduce nutrient build-up and eutrophication (Shutes, 2001; De Stefani et al., 2011). This type of integrated aquaculture-plant systems are commonly referred to as floating gardens or aquaponics (Blidariu and Grozea, 2011). "Fish manure is similar in its chemical composition to other livestock manures, and should be suitable for use as a plant crop fertilizer" (Naylor et al., 2011). Through harnessing the plant's capacity to utilise dissolved nutrients for growth, an easy filtration system can be constructed that has the ability to produce a consumerable product. It has been reported by Li & Li (2009) that incorporating aquatic plants on one-sixth of the surface area of fishponds could efficiently remove nutrients and improve water quality. Thus, floating gardens can fulfil this role by anchoring and suspending plants in enriched water adjacent to fish farming in cages (Fedunak & Tyson, 1997; Sikawa & Yakupitiyage, 2010). In this type of farming system the dam water is almost stationary and slow moving waters provide excellent retention periods for nutrient extraction by aquatic plants (Kratky et al., 2008). However, the dissolved oxygen levels have to be monitored regularly to ascertain whether there is enough for both plants and fish production.

Water stability of feed is important in the manufacturing of aquaculture diets (Paolucci et al., 2012; Sørensen, 2012). The water stability of such diets is greatly influenced by the properties of binders, and the ingredients themselves have a direct influence on the characteristics of the binders (Dominy & Lim, 1991). Therefore, feed and faecal integrity (less disintegration) have a significant influence on its water stability and hence capacity to withstand the leaching of polluting nutrients into effluent water (FAO/NACA, 2012). Any means of improving feed and faecal integrity will improve its effective sedimentation and removal through mechanical methods such as screening in through-flow and recirculation aquaculture systems. "The results of recent research on use of non-starch polysaccharides (NSP's) such as guar gum in aquafeeds to enhance the stability of rainbow trout faeces showed improved removal efficiencies of suspended solids and total phosphorous of about 40%, and of total organic nitrogen with 18 %" (Brinker, 2008). However, the ability of omnivorous fish species to digest NSP's e.g. tilapias, may limit its value as dietary faecal binding additive and requires further investigation.

The strategy and method used to deliver feed to fish can have a significant effect on the amount of feed wasted and the efficiency of feed utilization by fish. Thus feed efficiency management is highly relevant to the control of pollution in water bodies (Midlen & Redding, 1998). Therefore, the nature of the feeding regime can be regarded as a critical control point for adverse effects on water quality in aquaculture systems. Small-scale trout farmers in the Western Cape province used a combination of *"ad libitum"* and feeding programmes as primary feeding methods. This entails the administration of pre-determined quantities of artificial diets by hand to their fish stocks at regular intervals (mostly two to three times a day). Although it remains a less expensive option than technologically advanced automated feeders, the method has several disadvantages with regards to feed management and, consequently, the influence that aquaculture feeds have on water quality. Some small-scale farmers do not interpret the feeding behaviour of the fish correctly. They are inclined to feed fish too much to achieve rapid growth in order to attain market size earlier in the season. The benefit of this approach is less important than the potential adverse effects, namely the impact of wasted aquafeeds on the water quality of the pond. Also, the fish feeding routines of the small-scale farmers are often dictated by the availability of transport and the routines of their primary obligations and duties on the commercial crop farms. Disparities therefore exist between the fish's optimal physiological readiness for accepting feed and the actual availability of feed. As a result, fish are often fed under biologically sub-optimal conditions. The ideal feeding method may therefore be a demand feeding system (self-feeders), which allows the fish to control feed supply (Yue et al., 2008). Self-feeders rely on fish to activate a trigger that results in a release of food from a dispenser (Alanärä, 1992; Alanärä et al., 2001). Such feeders will reduce the amount of feed wasted and in return will have less of an adverse effect on water quality. During this study four mitigation measures were investigated, *inter alia*, improved feed management procedures, improved feed ingredients, demand feeders and floating gardens. When applied correctly, each of these measures has the potential to reduce organic pollution.

5.2 Materials and methods

5.2.1 Feed management

Data on FCR's were collected from the farms that kept production records and were evaluated for accuracy. The minimum, maximum and mean FCR's were calculated. These were compared with the general FCR for small-scale trout farming system with a carrying capacity of approximately six tons of final harvested weight. Finally, calculations were made of what savings on feed cost would be with every kg of feed saved, and what the associated reduction on environmental impact would be. The result was presented to the farmer as a simple visual indicator to the farmer which can be applied to calculate operational costs savings and provide an incentive to labourers and management to explore as motivation.

5.2.2 Feed ingredients

The researcher evaluated the effect of increasing levels of a guar gum based pellet binder on the feed and faecal matter of Mozambique tilapia *Oreochromis mossambicus,* based on the success of binders in trout diets. Tilapia has been identified as a warm water candidate species for net cage culture in irrigation dams. Treatments consisted of a control diet with increasing levels (0, 9, 17.5, 35.0 and 70.5 g kg^{-1}) of a commercial animal feed binder Duracube® (Bitek, Midrand) containing 170 g kg^{-1} guar gum. Binders were added in their powdery form to the diet ingredients, mixed and then hot water was poured onto the mixture. The mixture was then stirred thoroughly to form dough (Orire et al., 2010). It was further cold-extruded and dried at 60°C for 12 hours to decrease the moisture content and then stored (Ruscoe et al., 2005). Each tank containing a different level of binder was replicated four times and each treatment was evaluated for water stability as well as for effect on faecal stability. The amount of reduced leaching was calculated where faecal matter and uneaten feeds remained intact. The reduced impact on the environment in where minimum wastage occurred was evaluated (Brinker & Friedrich, 2012). Data were analysed using one-way ANOVA and Tukey's multiple comparison test with the level of statistical significance taken as $p < 0.05$ (SPSS v. 17 Spss Inc, Chicago, IL, USA). The results for tilapia were also compared with those found for trout as discussed in Brinker (2007).

Feed water stability:

The test was done in a system consisting of 100 stainless-steel test-containers with wire mesh tops and bottoms placed on an elevated chamber-grid (96 cm circumference) in twenty 25 litre chambers (5 test-containers per chamber) with a central airlift pipe which encourages turbulent water flow over containers (Figure 5.1). The chamber-grid was positioned to sustain the test-containers in top-water to ensure good water flow over feed samples. Feed samples were placed and weighed in the test-containers (approximately 20 gram feed sample per container). Following the water stability test dietary treatments were dried at 60 ºC for 16 hours in the test-containers after which final weight was recorded (Crous et al., 2010).

Faecal quality:

Twenty-four metabolic chambers were stocked with three fish each weighing approximately 40 gram each. Each chamber was fitted with a faecal collecting canister at its bottom. A 14-day digestibility trial was performed during which faecal quality was scored for visual appearance in terms of colour and length, as well as for its ability to reduce leaching of nitrogen and phosphorous. These findings were quantified by the observed concentrations of dissolved nitrogen and phosphorous. In order to limit mixing of feed and faecal matter, faecal matter was collected before feeding, and the un-consumed feed directly afterwards (Crous et al., 2010).

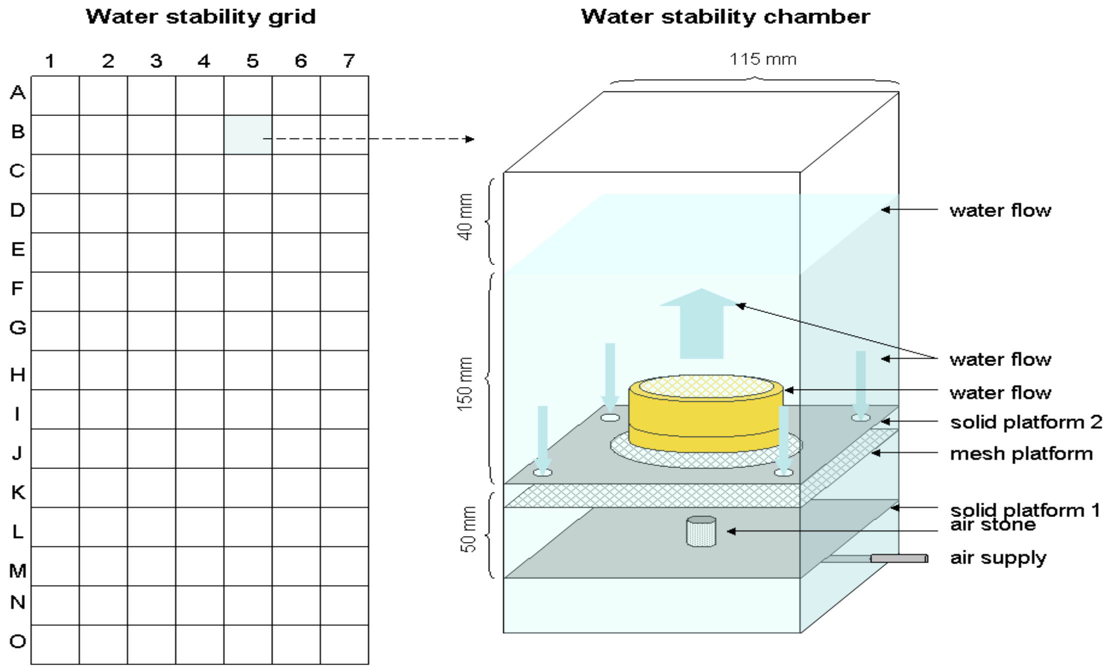

Figure 5.1. Water stability test chamber (Courtesy of Feedtech Group, Stellenbosch University, 2011).

5.2.3 Mechanical feeders

The mechanical feeding method (demand feeder) was compared to hand-feeding of fish. Hand feeding was conducted according to a feeding programme and also feeding fish *ad libitum* on response (Hinshaw, 1999; Attia et al., 2012). The amount of feed saved through minimum wastage and the consequent influence on the FCR and SGR was evaluated. A pendulum-operated demand feeder was built by the research team. The construction was based on plans derived from publications as well as referring to unused commercial units at the experimental farm at Stellenbosch University (Muir, 1998). The plans and completed product is shown in Figure 5.2.

The goal was to build a pendulum-operated demand feeder that was easy to construct, inexpensive, required no power or batteries and could withstand the elements on a net floating cage system. Two pendulum demand feeders were implemented on opposite sides of a floating net cage system at a commercial rainbow farm. The feeders were monitored for two months. Unfortunately the farmer did not allow fish to be fed only by the demand feeder for fear of affecting the FCR and affecting the overall growth of his fish. The research period fell within the peak production on the farm and farmers usually took great care of ensuring they deliver a quality harvest. There were no other replicates implemented at any of the other fish farms. The approach to the research was adapted to the farmer's request and therefore fish were fed using a combination of providing feed with a demand feeder and feeding by hand *ad libitum*. The practical implementation, performance and management of the device were described according to information provided by the fish farmer. The results of the descriptive analysis were compared with those found in the literature and to the experience encountered by other fish farms.

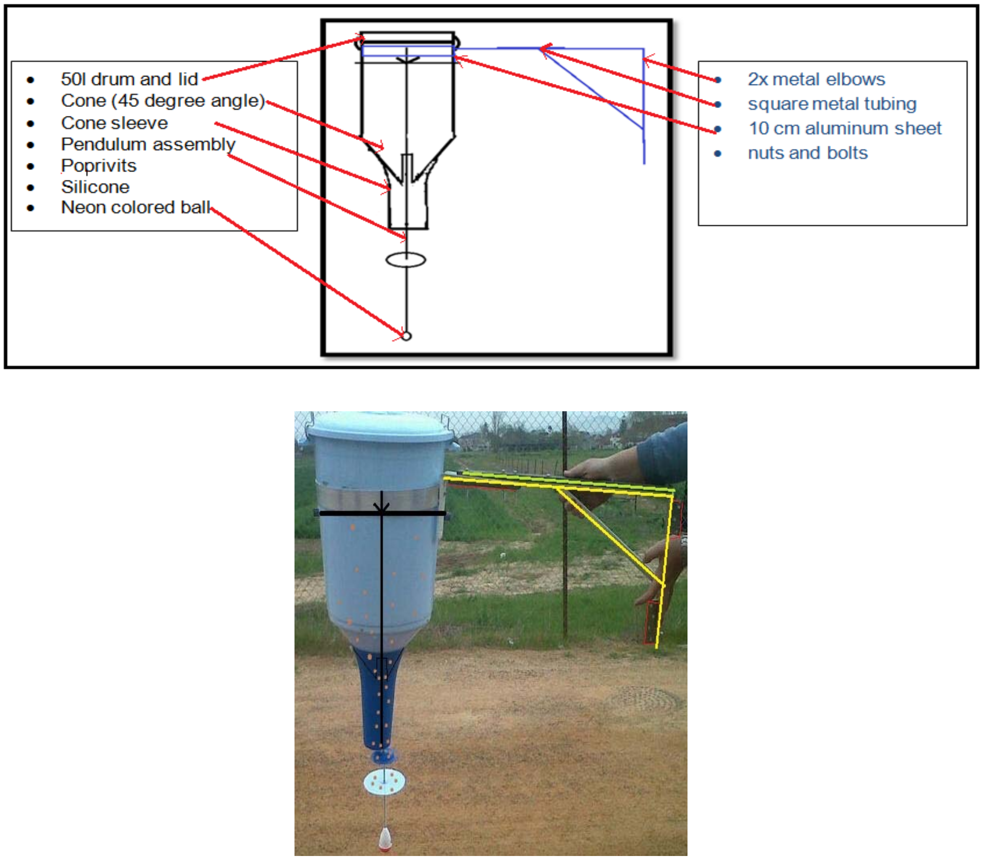

Figure 5.2. Illustration and picture of the demand feeder built by the research team.

5.2.4 Floating gardens

Floating gardens were incorporated in floating net cages without fish at only one farm due to cost constraints. Polystyrene flotation was used and holes were drilled to accommodate pots holding selected crops including a variety of lettuces, rocket and basil plants (Building a floating garden, [s.a]). Leafy plants were used of which the edible parts did not generally include the roots. Felizeter et al., (2012) explained that when plants are exposed to contaminated nutrient solutions that might enter water bodies via industrial and household wastes, the roots are likely to contain higher concentration of hazardous substances to humans, i.e. perfluorinated alkyl acids as the roots are suspended in the water. The floating gardens were monitored for nine weeks. Site visits were conducted weekly during which the performance of the system under prevailing climatic conditions was evaluated. During each visit, the plants were weighed and notes were taken on the general appearance and condition of plants, presence of pests and root biomass formation. The extraction rate of parameters such as N and P were calculated. The samples were taken before the plants showed any signs of going into the seeding phase. The whole plant, including roots, stems and leaves, was sent to BEMLAB in Somerset West to determine the chemical composition of the plant according to the standards of Ako & Baker (2009). Water samples were taken every four weeks during the trial period to determine if there was any change in the concentrations. The samples were sent to BEMLAB for analysis. In

Fig. 5.3 and 5.4 illustrations of floating gardens are shown and it can be noticed that this type of farming system has been practised centuries ago by the earlier Aztec civilisations.

Figure 5.3. Illustration of a floating garden in a fish pond. (Courtesy of Gail Gates, www.pondplantgirl.com, 2012).

Figure 5.4. Illustration of earlier Aztec floating gardens.(Courtesy www.pondplantgirl.com, 2012).

5.3 Results and discussion

5.3.1 Feed management

The FCR's and SGR's of the 14 production sites for 2009 are presented in Figure 5.5. The reason for choosing the year 2009 is the fact that this year had the largest number of operational projects during the study period. The mean FCR is 1.96 ± 1.15 and the mean SGR is 1.00 ± 0.37. The lowest FCR recorded was 1.17 and the highest 4.81. Pradhan et al. (2012) cite FCR's of 1.66-2.63 for trout farms in Nepal, while Danish farms are not allowed by regulation to exceed FCR's of 1. Theoretically FCR's of 0.8-1.0 are possible with high oil diets (Jokumsen & Svendsen, 2010). The trout farms in Denmark are also regulated with maximum allowable annual feed quotas, thus encouraging farmers to achieve optimal feed utilization. Lansdell (2010) has written feed management procedures and guidelines proposing a management system for responsible aquaculture. Fish farmers are expected to achieve significant improvement in their management if they comply and follow these guidelines. However, the success of such strategies and guidelines still requires further investigation. Both documents are presented in Appendices 4 and 5.

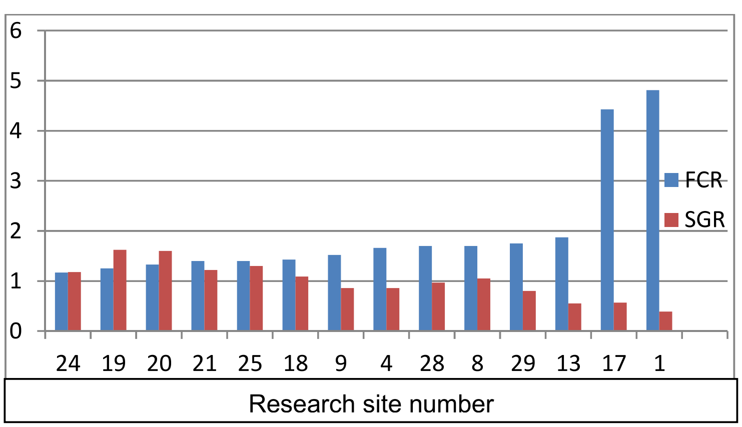

Figure 5.5. The average FCR and SGR of the 14 sites as recorded in 2009.

5.3.2 Feed ingredients

Feed water stability:

There were no significant changes in the feed water stability with an increasing level of binder ($p>0.05$). In Fig. 5.6 the 16-hour water stability treatments are indicated. This could possibly be explained by the binder's effect on extrusion dynamics. During manufacturing of the test diets it was observed that high levels of binder addition increased extrusion temperature, probably due to the high-hydration character of guar gum - thereby retaining water from the gelatinization process as water addition was kept constant over all treatments. Visual assessment of faecal length showed no significant differences ($p>0.05$) in for either length or colour. However, faecal matter tended to become lighter at high level of binder inclusion, which can possibly be explained by increasing digesta viscosity (Amirlolaie, 2005; Crous et al., 2010).

Faecal quality:

Water analysis and visual assessment of faecal length and colour showed no significant difference ($p>0.05$) between treatments. The tendency of faecal matter to become lighter (Fig. 5.7) with increasing levels of binder inclusion may possibly be explained by an increased gut emptying rate due to the viscous nature of the soluble fibre component of the binder. In addition, the level of binder did not influence the digestibility of the experimental diets. Unlike rainbow trout (mostly carnivorous), tilapias (mostly omnivorous) have a better ability to digest NSP's - therefore inert faecal binding solutions should be investigated for use in tilapia feeds (Crous et al., 2010).

5.3.3 Mechanical feeders

Initial results indicated that fish responded to the self-feeder within three days after installation. However, it was also observed that the feeder was activated unnecessarily through wind and wave action. This resulted in overfeeding and feed wastage for fish accustomed to be fed only when hungry. Wurtsbaugh & Davis (1977) when unlimited feed was released, the bite frequency reached a level at which the trout were unable to eat all the released pellets. Also, innate behavioural responses triggered by, for example, the presence of feed or other fish feeding, rather than by actual hunger, could be the reason for some feeding activity in fish with access to unrestricted demand feeders. This can lead to feed being released unnecessarily, resulting in feed waste and poor FCR (Alanärä, 1992).

Mohapatra et al., (2009) stated that Indian major carp, *Labeo rohita*, reared in outdoor culture systems where the pendulum demand feeder was not affected by wind and wave action, had growth rates 12.61 % higher when fed with demand feeding systems compared to fish fed by hand. Furthermore, the efficiency of demand feeding with regard to the FCR was found to be better for rainbow trout than when feeding by hand (Alanärä, 1992). These studies showed the value of demand feeders to overall improvement in feed management when the devices are working well. However, the prevailing weather conditions need to be taken into account when conducting such evaluations. Table 5.1 indicates the SGR and FCR for different methods of feeding. The FCR of 1.08 for the restricted demand feeder was the best and indicated the importance of minimising overfeeding of fish.

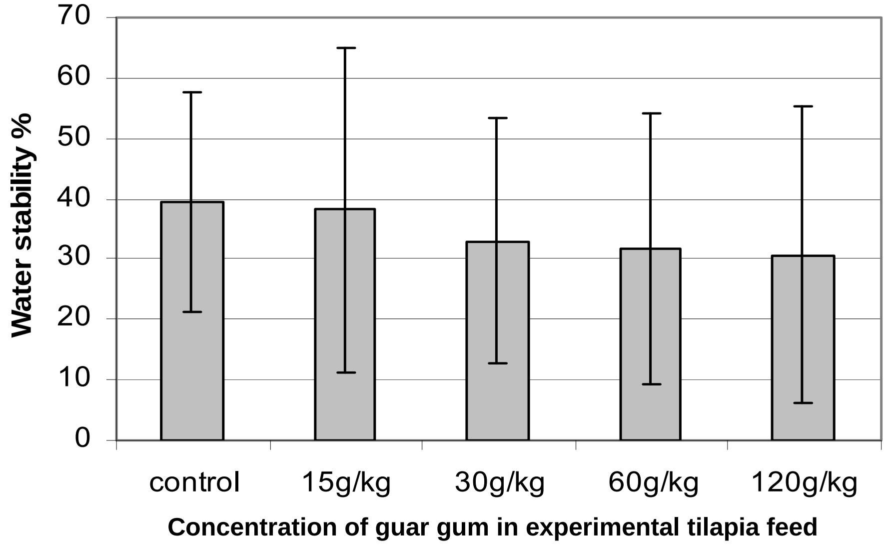

Figure 5.6. The 16-hour water stability of the dietary treatments.

Concentration of guar gum in experimental tilapia feed:

control 1.5 mg kg^{-1} 3.0 mg 6.0 mg 12 mg kg^{-}

Figure 5.7. Influence of guar gum concentration on length and colour scoring of faecal matter.

Table 5.1. SGR of rainbow trout (weighing 1.0-1.2 kg) expressed as % per day and FCR within feeding regimes (Alanärä, 1992).

Feeding regime	**SGR**	**FCR**
Timer-restricted	0.72	1.36
Demand feeding – restricted	0.87	1.08
Demand feeding – unrestricted	0.93	1.49

5.3.4 Floating gardens

The polystyrene-based floating garden provided a stable platform for the pots housing the plants. Of all the plants used the lettuces performed the best. Plant mortalities were minimal. Plants died when they were dislodged by the force of the wave action beneath the rafts pushing the plants upwards through the holes. Plants that were replanted did not recover completely and their growth was stunted. The plants that survived grew well and there was significant growth in leaf number and size. Most of the growth was observed in the root section of the plants (Fig. 5.8).

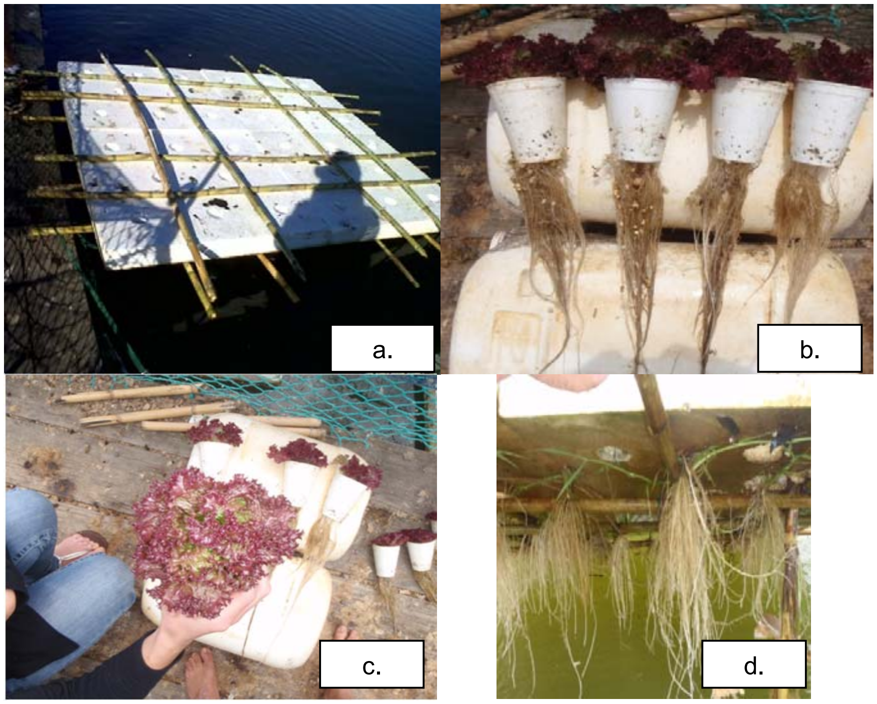

Figure 5.8. Polystyrene raft (a), root formation in lettuce (b), leaf foliage of the lettuce (c) and roots on bamboo shoots (d).

In Table 5.2 it is shown that the plants grew well. The mean weight increase over nine weeks is 95.10 g ± 43.50. In Table 5.3 the chemical analysis of the plants is shown. It indicates that there was an uptake in the primary macronutrients (N, P, K) and secondary the macronutrients (Ca, and Mg). Other micronutrients such as B, Cu, Fe, Mn and Zn were also utilised by the plants. Dediu et al., (2012) found that lettuce registered a greater amount of both biomass and yield in low flow treatments. They found the average weight gain to be 75.49 g. However, this was recorded over a three week period. TAN removal rate should be in the range of 0.24 to 0.64 $g/m^2/d$ (Eding et al., 2006; Lyssenko & Wheaton, 2006). The removal rate of TAN for lettuce was 0.27 $g/m^2/d$. For the production of 3.5 kg/m^2 lettuce, a ratio of 1.09 plants/fish (1.84 g feed/day/plant) is required to limit the accumulation of residual nutrients in a fish farming system (Dediu et al., 2012). The P concentration decreased from 0.157 mg/L to 0.071 mg/L over a nine week period, which amounts to 0.001 mg/L/day. In their study Trang and Brix (2012) reported update values of 0.002 g/day by lettuces.

The available nutrients as recorded concentrations of the water quality parameters during the study are indicated in Table 5.4. For the plants to survive on the raft it is crucial that the nutrients in the water must be in the correct molecular form and concentration. Through the action of bacteria around the roots of the plants these nutrients can be transformed into usable molecules. All the parameters, except pH and TAN showed a decline in concentration as indicated in Table 5.4. However, due to the scale of the trial, it was difficult to qualify the decline due to the presence of the floating garden. The importance of other bio-chemical processes should also be considered for nitrification and oxidation of ammonia to nitrite and then to nitrate is essential for development of plant biomass (Cockx & Simonne, 2003). The nitrate concentration of 0.25 mg/L (see Table 5.4) is relatively low in terms of the requirements of plants to produce significant foliage and root biomass.

Table 5.2. Weight of the individual plants at planting and at harvesting. The initial weight is measured with seeding soil and the initial clean weight after the soil has been was washed off. Harvested weight included all the plant parts.

Sample no	Initial weight (g)	Initial clean weight (g)	Harvested weight (g)	Weight increase (g)
1	12.00	3.00	90.00	87.00
2	14.50	5.50	149.00	143.50
3	14.00	5.00	136.00	131.00
4	10.00	1.00	36.00	35.00
5	10.00	1.00	80.00	79.00

Table 5.3. Chemical analysis of harvested plants.

Sample no	N %	P %	K %	Ca %	Mg %	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
1	1.70	0.14	2.17	0.97	0.39	3774	978	6782	24	42	24
2	1.94	0.24	2.60	1.01	0.41	2726	779	10268	54	57	25
3	2.01	0.14	2.11	0.96	0.36	2915	785	8863	60	47	23
4	1.82	0.12	1.98	1.18	0.45	2463	927	11074	39	51	25
5	1.62	0.12	1.63	1.30	0.52	2202	561	9256	36	40	19

Table 5.4. Water quality results for the physico-chemical parameters of the dam.

Parameter	Sample 1	Sample 2
pH	7.9	8.3
EC mS/m	52.1	50.5
Na mg/L	68.6	67.1
K mg/L	8.05	6.53
Ca mg/L	25.99	19.19
Mg mg/L	15	12
Fe mg/L	0.56	0.69
Cl mg/L	123	96.2
CO_3mg/L	12.1	18.1
HCO_3mg/L	79.62	73.43
SO_4mg/L	24.28	19.41
B mg/L	0	0.02

Parameter	Sample 1	Sample 2
Mn mg/L	0.221	0.018
Cu mg/L	0	0
Zn mg/L	0.1	0.01
P mg/L	0.157	0.071
PO_4mg/L	0.48	0.22
TAN mg/L	0.42	0.54
NH_3-N mg/L	0.008	0.001
NO_3-N mg/L	0.29	0.25
NO_2-N mg/L	0.019	0.01

5.4 Conclusion

Aquaculture can have a negative effect on the environment and can influence freshwater ecosystem functioning. However, if optimal volume and flow rates in production systems are maintained the impact can be drastically reduced through regular water replacement (Soofiani et al., 2012). Fish farming of rainbow trout has the advantage that the production season coincides with the winter rainfall in WCP of South Africa when dams are filled to capacity. In addition, farm management has to take responsibility to plan and implement mitigation to reduce organic pollution and achieve sustainable aquaculture practices. In cases where appropriate and effective mitigation was implemented, it reduced aquaculture's impact on the ecosystem (O'Beirn & O'Brien, 2011). The rationale is that any measure that reduces pollution improves the overall ecologic status of the water body.

In order to facilitate sustainable aquaculture practices for small-scale community-based fish farming, procedures have been written to guide farmers (Landsdell, 2010). The challenge is to make these accessible and comprehendible at farming level where the fish farmers have different education. Bhujel (2012) argues that education and training systems are important to ensure success in aquaculture livelihood enterprises and therefore proposed that aquaculture curricula should be incorporated at secondary and tertiary institutions. I concur with this perspective and it is envisaged that the message would be communicated to aquaculture training institutions.

"As feed is responsible for most of the environmental impacts, it can be extrapolated that an improvement in the overall FCR's will have a positive impact on all the important environmental indicators" (d'Orbcastel, 2009). The mean FCR for fish farmers in the WCP was 1.96 ± 1.15. Farmers were using juvenile trout of about 0.2 kg for growing out and sold fish to the market at approximately 1. 2 kg. Thus the weight gain was 1 kg. Farmers were stocking 6000 fish and using on average 11760 kg of feed for the production season (Salie et al., 2008; Stander et al., 2011). If farmers could reduce/improve their FCR by 0.1 (i.e. from 1.96:1 to 1.86:1) it would translate into a saving of 600 kg of feed (5 %) or 100 kg per ton of fish produced. The estimated waste output from rainbow trout cage farms per ton of fish produced is given as total solids of faecal and feed origin (236.0 kg), solid nitrogen (12.8 kg), solid phosphorous (5.3 kg), dissolved nitrogen

(41.3 kg) and dissolved phosphorous (3.4 kg) respectively (Azevedo et al., 2011). Thus a 0.1 decrease in the FCR would result in 5% less nutrient loading. The management system for responsible aquaculture nutrition is indicated in Appendix 3. Good management practices for sustainable aquaculture were also supported by the Freshwater Trout Aquaculture Dialogue initiative (FTAD, [s.a]).

The guar-gum based binders did not make significant improvement in the water stability of the feed and the faecal quality for tilapia. The reason could be that tilapia has the capacity to digest non-starch polysaccharides and therefore guar-gum based binders did not present a good solution for stabilizing faecal matter. However, guar-gum binders did improve the water stability and faecal quality of rainbow trout diets. Improved feed quality can reduce nutrient leaching in the water and allow the removal of suspended matter via mechanical methods such as waste suction and hydroclonic filtering systems. Therefore use of appropriate binders for different fish species could enhance water stability of feed and faecal material quality.

Demand feeders (self-feeders) were used to give fish access to feed when triggered on demand. This ensures that fish will feed according to appetite and that minimum quantities go to waste. The construction of a pendulum-based demand feeder indicated a feasible option in terms of cost and level of ease of building. However, usage on cages in open water systems was not practical because external factors, such as wind and wave actions, triggered the feeder unnecessarily and released feed not utilized by fish. Farmers did not benefit from such mechanical feeders. Observations and results of tested demand feeders led to the conclusion that models that could withstand influence of wind and wave action need to be developed.

Heavy wind storms and wave actions made it difficult to implement and monitor the floating garden system. For the lettuce to survive in water-based agriculture, the dam has to provide growth conditions and nutrient quality similar to that found in land-based agriculture. The first goal was achieved in that a practical and economical floating garden was constructed. The second goal namely to determine whether or not plants could survive and grow was also achieved, but due to the nature of the project, not enough data on the plant growth were collected. However, it was possible to collect data and practical knowledge on the design and construction of floating rafts.

The growth for lettuce was slow due to harsh weather conditions. During the study growth was achieved in nine weeks very similar to what Dediu et al, (2012) achieved in three weeks. However, the floating garden presented good plant biomass for a system in an irrigation dam. Dediu et al., (2012) found that lettuce registered a greater amount of both biomass and yield in low flow systems. TAN removal rate should be in the range of 0.24 to 0.64 g/m^2/d (Eding et al., 2006; Lyssenko & Wheaton, 2006). The removal rate of TAN for lettuce is usually 0.27 g/m^2/d. For the production of 3.5 kg/m^2 lettuce, a ratio of 1.09 plants/fish (1.84 g feed/day/plant) is required to limit the accumulation of residual nutrients in a fish farming system (Dediu et al., 2012). Thus for typical small-scale trout producing system housing 6000 fish, 6540 lettuces would be required. This explains why there was not any decline in the concentration of TAN at the stocking rate of plants and the volume of the irrigation dam. The scale of the trial did not allow sufficient analysis to be done to ascribe decreases in concentration of parameters to the presence of the floating garden. Furthermore, the role of oxidative biological processes such as nitrification and ammonification needs to be considered. These processes form nitrite and nitrate respectively and are vital for the growth of aquatic plants (Cockx &

Simonne, 2003). Therefore the dynamics of the water chemistry associated with nitrification and ammonification requires additional study.

There is a good case to further investigate the potential of herbs (parsley, basil, celery, coriander) and cut flowers as floating garden crops for these are considered sellable crops if it can be produced in large volumes and of good quality. An increase in the size and stability of the floating garden would also make higher stocking densities possible (32 plants per m^2 were used). Due to the improvements made to the rafts during the study, there was an unexpected result. River reeds (*Phragmites* sp) were used to improve raft stability. Root growth was observed from the nodes. Roots tripled in biomass within three weeks. Stem and leaf growth was minimal but after three weeks stems of up to 30cm were observed. The fact that the reeds indicated growth might have had a negative effect on the growth of the lettuce due to competition for nutrients. The growth of both lettuces and reeds confirmed that plant growth can be sustained as floating gardens and they can be expected to reduce nutrient concentration of farm dams.

It was shown in the study that mitigation can be incorporated to reduce organic pollution and improve water quality. However, this was an investigative research project and only provided the basis for follow-up research. The real benefit would be realised when the extent to which water purification takes place can be quantified.

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CHAPTER 6: Role and function of freshwater aquaculture in rural and peri-urban farming communities

Abstract

Aquaculture in South Africa is still perceived to be driven by high value species and having a deteriorating effect on the environment. This is in contrast to global aquaculture where substantial growth and development are experienced by many developing countries. Globally most farmed fish are grown in small-scale production systems to the benefit of local communities. Aquaculture is the fastest growing food-producing sector in the world and provides opportunities for livelihood creation. South Africa needs to promote a “blue revolution” in order to achieve a “green economy”. This study investigated the role and function of freshwater aquaculture in farming communities. Twenty-one freshwater farmers in the Western Cape province of South Africa were interviewed. Data were collected via structured questionnaires and informal discussions. The results indicated that aquaculture can make a meaningful contribution to the average household income. It was considered to be a viable enterprise opportunity. Most of the respondents indicated that their understanding and appreciation for the potential of aquaculture, have improved. However, access to knowledge and information was indicated to be a constraint. Other main challenges to practicing aquaculture were access rights to water bodies and maintaining good quality water for their fish population. The lack of development funding and start-up capital was listed as the third constraint. The study indicated that famers were aware of the positive contribution aquaculture can make to farming communities and called for wider institutional support from the private and public sector to create an enabling environment for the aquaculture development.

6.1 Introduction

Aquaculture provides opportunities to farmers to help them cope with adverse conditions and adapt to climate change by integrating aquaculture and agriculture (Efole Ewoukem et al., 2012). In this process farmers are increasing their livelihood options and household nutrition (FAO/NACA, 2012). Aquaculture is the fastest growing food-producing sector in the world and is uniquely placed to reverse declining fish supplies from capture fisheries (Subasinghe et al., 2009; Pauly& Froese, 2012). This industry has been supplying meaningful jobs and livelihood opportunities to many people across the world. “Fisheries and aquaculture provided livelihoods and income for an estimated 54.8 million people engaged in the primary sector of fish production in 2010, of whom an estimated seven million were occasional fishers and fish farmers” (FAO, 2012). Furthermore, the exponentially growth of aquaculture has contributed significantly to alleviating malnutrition and poverty in developing countries (Thompson et al., 2011; Ahmed et al., 2012; Nasr-Alla et al., 2012). In many sectors subsistence aquaculture is regarded less important although most farmed fish and shellfish are grown in traditional small-scale systems that benefit local communities and minimize the environmental impact (White et al., 2004). Small-scale aquaculture has definitely contributed to the success and growth of the global industry for the risk of failure is spread much wider and increases the chances of viable ans sustainable operations.

The need to promote aquaculture in Sub-Saharan Africa has become more urgent through increasing rural-urban migration (7-10%/yr) and the occurrence of declining fish supplies from capture fisheries (Jarlov, 2000). In order for government, donor agencies, and others to begin addressing vulnerability and poverty, they need to recognise urban growth in Sub-Saharan Africa and accept that poverty exist in both rural and urban areas (Maxwell et al., 2000). “In order to enhance aquaculture’s development, there is need to understand the driving forces of its uptake, its scope to positively contribute to poor livelihoods, increase fish supplies and food security in relation to production resources, farming systems, market structures, institutional capacities, dissemination strategies and government policies and strategies” (Halkatti et al., 2003; Dobson, 2012). Develoment practitioners need to comprehend the importance of the link between food security status and household income in order to facilitate strategies to address these challengers. Therefore iintervention is required to understand the complexities imbedded in these processes and systems in order to determine the lessons learned from aquaculture initiatives and to evaluate opportunities and challenges presented to these communities. The approach can further be strengthened in South Africa through local and international collaboration on training, demonstrations and participatory research (Spies, 2002).

Since 1994 (birth of democracy) the South African government has embarked on extensive political, economic and social transformation to encourage a society where more inclusivity is postulated for those who had been historically disadvantaged (Marais, 2011). The fishing and agricultural sectors achieved this through the restitution of rights to resources (e.g. land and marine resources) that communities had lost or had been denied as well as the re-distribution of wealth and resources driven by legislation and policy (DEAT, 2004; Nielsen & Hara, 2006).

Overal objectives of this study were to evaluate perception and understanding of freshwater aquaculture with reference to resource distribution, value chain aspects, and associated opportunities and constraints. Furthermore, it investigated ways to promote strategies for sustainable aquaculture as a means to improve livelihoods and reduces poverty and food insecurity. The study also assessed the capacity of farmers to promote uptake and knowledge acquisition.

6.2 Research methods

The surveys were limited to the WCP of South Africa. The WCP forms the hub for both the capture and the aquaculture industries in South Africa. Conducting the survey in this province would therefore provide a good indication of the role and function of aquaculture in the livelihood of farming communities. However, the fact that the survey was limited to this one province cautions one from applying the findings to the rest of the country unquestioningly. An aquaculture producer survey was designed and carried out using a structured questionnaire, designed according to guidelines presented in Hunston & Oakey (2009). An example of the questionnaire is shown in Appendix 7. In the surveys the following variables were investigated and analysed:

1. Type of farming system.
2. Land title and ownership.
3. Farming purpose.
4. Type of fish farmed.
5. Responsible for selling.
6. Main paying customers.
7. Constraints to production.
8. Marketing constraints.
9. Point of sale.

Additional information that was not covered within the scope of the structured questionnaire surveys was solicited and recorded through one-on-one informal discussion with the respective farmers. Results were analysed by SPSS 13.0 for Windows for frequency of occurrence (SPSS Inc., Chicago, IL, USA) as described in Brymer & Cramer (2005).

The study included 21 freshwater aquaculture farmers (both small and larger scale) covering a range of candidate species. It was decided to include a wider spectrum of freshwater species in order to gain a broader perspective from a range of farmers. Most of the issues listed were important to all the farmers irrespective of the species under production. At least one established farmer for each freshwater aquaculture species farmed in the WCP was interviewed. The species farmed in WCP were rainbow trout, ornamental fish, freshwater crayfish (marron), tilapia (still in research and development stage), salmon smolts, catfish, crocodiles, and eels. Information was also obtained on farming of aquatic plants such as water hawthorn (“waterblommetjies”). The selected 21 farms provided a good sample for the study for in the WCP there are 43 operational farmers of which 31 are trout producers (DAFF, 2012). For each variable a frequency of occurrence is graphically depicted as a percentage. A descriptive discussion of the respective percentages for each variable was provided.

6.3 Results and discussion

A multitude of prominent farming systems were used by the freshwater farmers. The predominant one was the land-based earthen ponds. The second most prominent was floating cages. These cages were found to be used in irrigation reservoirs and were primarily utilised for rainbow trout farming. Some farmers conducted farming in a combination of systems such as raceways and earthen ponds as well as tanks, ponds and cages.

Thirty three percent (33%) of the respondents used pond farming systems (Fig. 6.1). Ponds, whether earthen or plastic, are widely applicable for aquaculture and can be used for a number of candidate species such as trout, catfish, tilapia and marron. This type of farming system can be sustainably used in rural areas where abundant land is available.

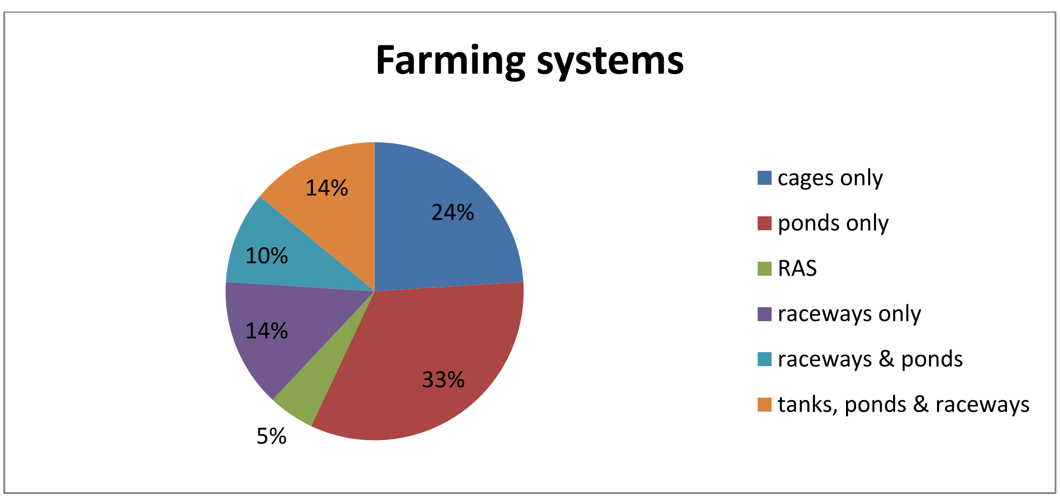

Figure 6.1. Farming systems used by respondents.

The second most common type of system in use was cage systems (24% of the respondents). Cages are characteristic of trout farming operations. Although cage farming in South Africa is mostly limited to trout, the WCP has a network of irrigation dams that have potential for farming other species such as tilapia and catfish (Salie et al, 1998; Maleri, et al., 2008; Maleri, 2011). The cage production system has proven to be the most economical culture unit provided optimal water quality is maintained (Pillay & Kutty, 2005, Beveridge, 2004). The least-used systems were re-circulation aquaculture systems (RAS) and land-based tanks. The cost associated with recirculating systems and tanks is high for energy and construction (Schneider et al., 2006; Martins et al., 2010). Further investigation and promotion are required to look at the potential of recirculating aquaculture systems as the pressure on the natural environment for aquaculture increases.

The land title and ownership of the aquaculture projects were captured in Figure 6.2. Of those surveyed 39% rented the land and/or water resources from government. One of the reasons for this is that access to privately owned water on privately owned land is difficult for emerging black farmers (Salie, 2011). Generally black farmers target resources under the jurisdiction of the local authorities (municipalities). Local economic development policies favour such applications. The second most common types of land ownership were those who owned their own farm or farm workers who rented land/dams from commercial farm owners. Farm workers have the advantage in that the land owners were investigating ways to help their workers earn additional income. In the case of aquaculture, the use of irrigation dams were made available where an aquaculture enterprise seems to have the potential for generating alternative income and skills development for their farm workers.

“The form of title to land is regarded as the single most important aspect of sustainable aquaculture” (Palmer et al., 2012). In view of South Africa’s history, land ownership will always be a key issue for development of aquaculture and to broadening participation in the agricultural industry (Adams et al., 1999). In some cases, government, especially local councils and municipalities, hold title to land within their jurisdiction. Most successful aquaculture operations were found to be where a strong ownership culture was present.

The establishment of the free-market economy in the early 1990’s in South Africa has provided many business opportunities to the local as well as regional communities (Tupy, 2012). It has led to diversification in trading options. Figure 6.3 indicate the priority and motivation of the respondents for embarking on aquaculture projects. Most of the respondents (71%) farmed fish for the wholesale market. The trout operators are known for farming fish for the processing factories. Most farmers realize that in order to increase their profits, they have to become involved in value adding. Presently, value adding is constrained by the absence of institutional support structures, lack of capital and lack of interest from existing processors for joint venture and partnership initiatives.

The supply chain of freshwater farmed species presents numerous opportunities to farmers. As farmers’ confidence grows in producing quality fish products, they are expected to investigate ways of diversifying their operations. Such interventions could be exploring smaller niche markets for fresh and processed fish, such as food and catering outlets. The accompanying outreach and awareness will lead to the overall development of the aquaculture sector.

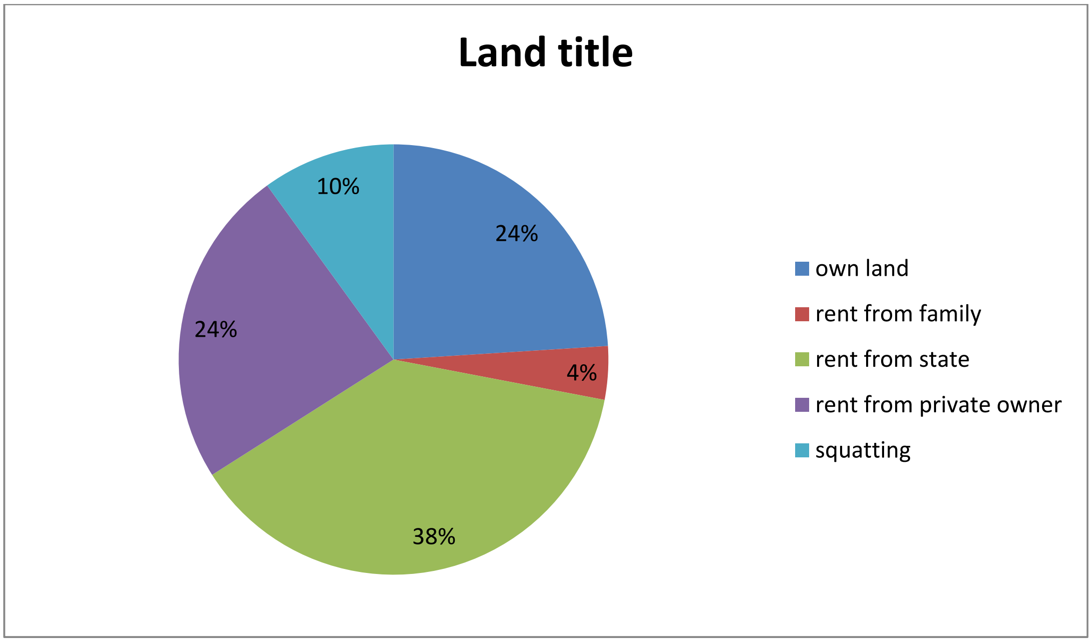

Figure 6.2. Land title and ownership for the aquaculture projects.

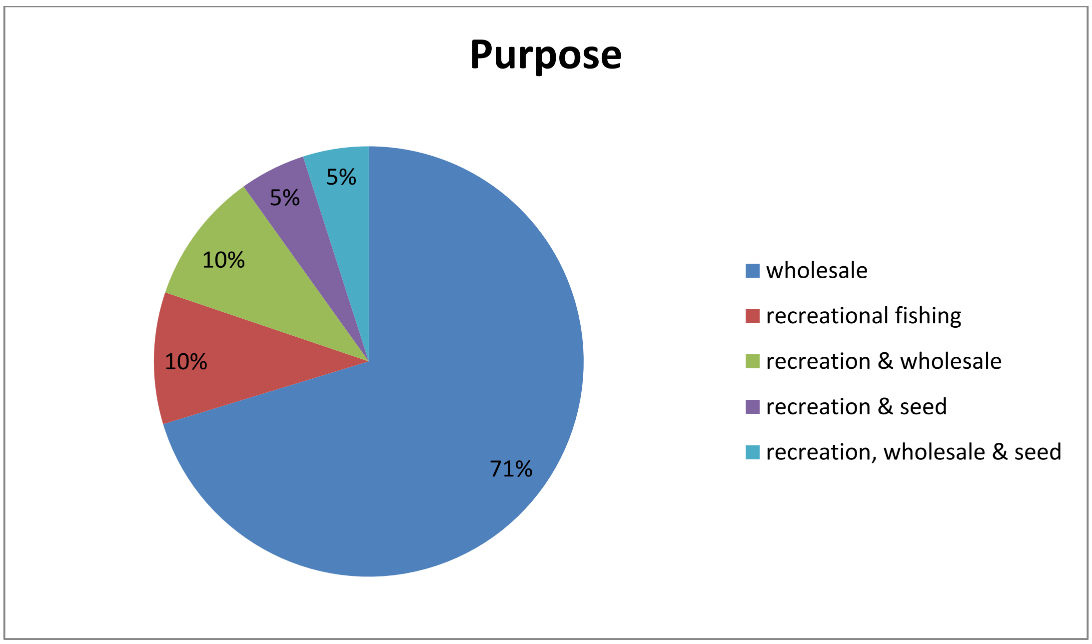

Figure 6.3. Motivation of the farmers for embarking on aquaculture projects.

The other purpose for farming some of the species was to provide live fish for on-growth initiatives or for the recreation sector. Many of the irrigation and other reservoirs were stocked with juvenile fish. In recent times the rainbow trout farming sector has grown and is linked with the promotion of angling and ecotourism in South Africa (Stander et al., 2011). Most of the farms producing for the recreation market were mainly those on the main tourist routes and it was clear from the survey that most were switching from sole production for direct human consumption to combining this with production for the recreation/tourist market.

Rainbow trout was the dominant species farmed in the Western Cape (42% of the respondents) followed by ornamental species and abalone. Trout is produced in cage systems on irrigation dams scattered across the province and is the most successful farmed species in the province. In this context, the species provides the best chance for future growth and extension of freshwater aquaculture. Future growth will depend on how the network of potential viable dams and infrastructure are developed to meet increasing demand. Ornamental fish include species such as goldfish, cichlids, koi and a variety of tropical species. No polyculture systems were recorded where more than one species are farmed together and complement a symbiotic existence. It is also referred to as aquaponics where fish and plants are farmed together (Rakocy, 2012). Polyculture systems under investigation for future development were presented in Chapter 5 where trout and floating gardens were investigated. Marron is also thought to present potential as a polyculture species with rainbow trout (Gavine & Gooley, 2003). The promotion of the research and development for these systems is currently hampered by the lack of enabling legislation. In addition, government authorities are finding it difficult to create a legislative framework to allow and manage the production of exotic species, such as Nile tilapia (*Oreochromis niloticus*) in the country (Van der Waal, 2002). A breakdown of the dominant species farmed is given in Figure 6.4. Species regarded as novel to aquaculture include crocodile, eels and marron (freshwater crayfish). Only a few farms were producing these species with eels for aquaculture still under research. The promotion of new candidate species is influenced by marketability as well as a national policy, which only promotes indigenous species.

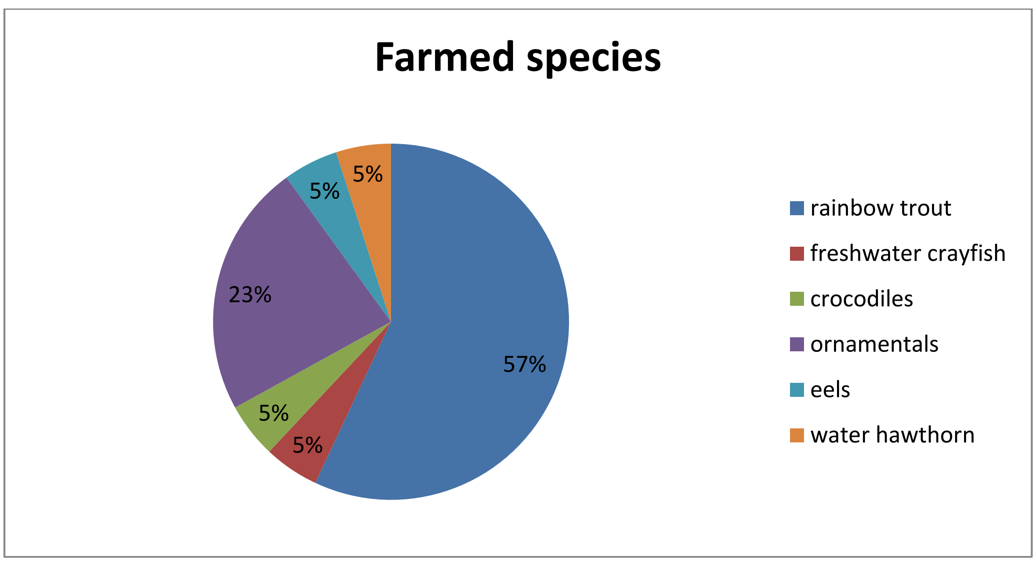

Figure 6.4. Type of species farmed by the respondents.

The majority of farmers (61% of the respondents) took the responsibility to sell their produce (Fig. 6.5). This has given rise to independent marketing strategies usually characterized by individualistic attitudes and simultaneously created a paternalistic environment. The negative side of such strategies is that market information and networks were seldom shared and lead to unnecessary and costly duplication of conducting research and gaining market intelligence. This resulted in high transaction costs for farmers and the sector as a whole. The small-scale trout producers (producing <15 tons) have instituted a co-operative structure to facilitate marketing and improve service delivery to their members. This has proved successful and has resulted in pre-arranged delivery agreements with processors, successful sourcing of venture capital for emerging farmers and technical support agreements with aquaculture promotion institutions (Salie, 2011).

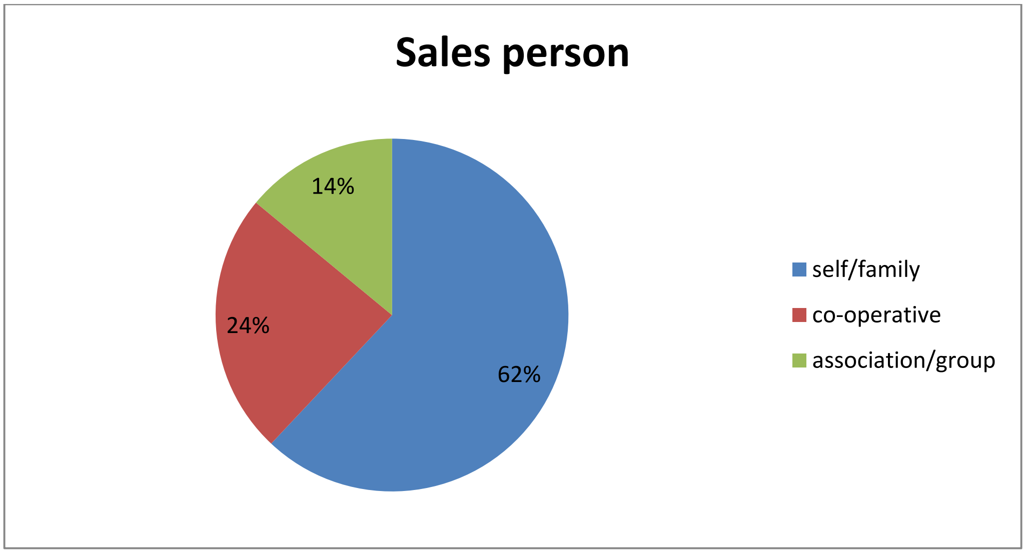

Figure 6.5. Responsible party for selling farmer's produce.

The producer survey also probed the question of who the main paying customers for aquaculture products were. Figure 6.6 indicated that customers are spread across a variety of outlets with sales directly from farmers to processors giving the highest count (27%). Although this is a convenient way of marketing, it is also the least profitable. Other sales are generated through delivery to wholesalers nationally and agents abroad. The rest of the paying customers comprised of the restaurant and hotel sector and deli shops in shopping centres.

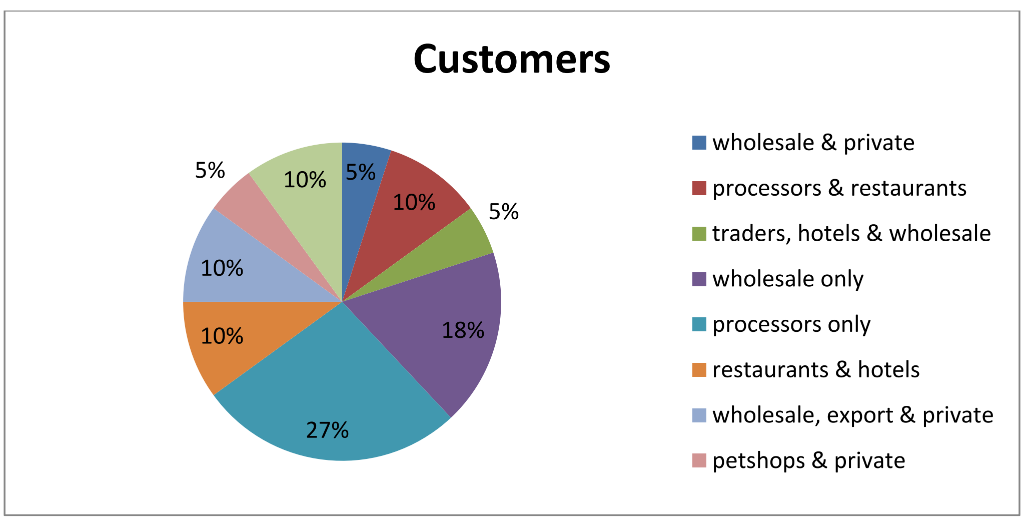

Figure 6.6. Main paying customers for aquaculture products.

The main constraints to aquaculture's development and growth for farmers are expressed in Figure 6.7. The main constraints in order of priority were water, knowledge and investment capital. Challenges associated with water include a range of issues varying from the absence of regulatory legislation to fluctuating water quality for production. In the last few seasons, the Western Cape has been experiencing relatively dry winters and there were insufficient rains to fill the dams. Water restrictions have been imposed, and as a result, more pressure is being exercised on its sustainable utilization and management. Aquaculture impact studies have been conducted and numerous guidelines to management of water resources have been written (Du Plessis, 2007; Maleri et al, 2008; Maleri, 2011; Nel, 2012). In the past, aquaculture has been seen as a polluting factor, and in general, detrimental to the environment. This view has changed and more evidence was provided whereby it is recognised that when aquaculture is conducted within target water quality ranges, it can contribute to sustainable livelihood opportunities with controlled and limited environmental impact (Gumbo, 2011; Maleri, 2011; Salie, 2011). Although the knowledge base for sustainable freshwater aquaculture in South Africa has improved significantly over the last 10 years, the challenge remains to transfer information successfully and more importantly to monitor the compliance of farmers to proven theory and practice. A number of tuition programmes are now available to students and farmers. Recent studies have indicated that farmers who have been trained and comply with guidelines show the most success in their operations (Salie et al, 2008). The onus is on combining education and training with sustainable industry development according to the national aquaculture strategy for South Africa (DAFF, 2011).

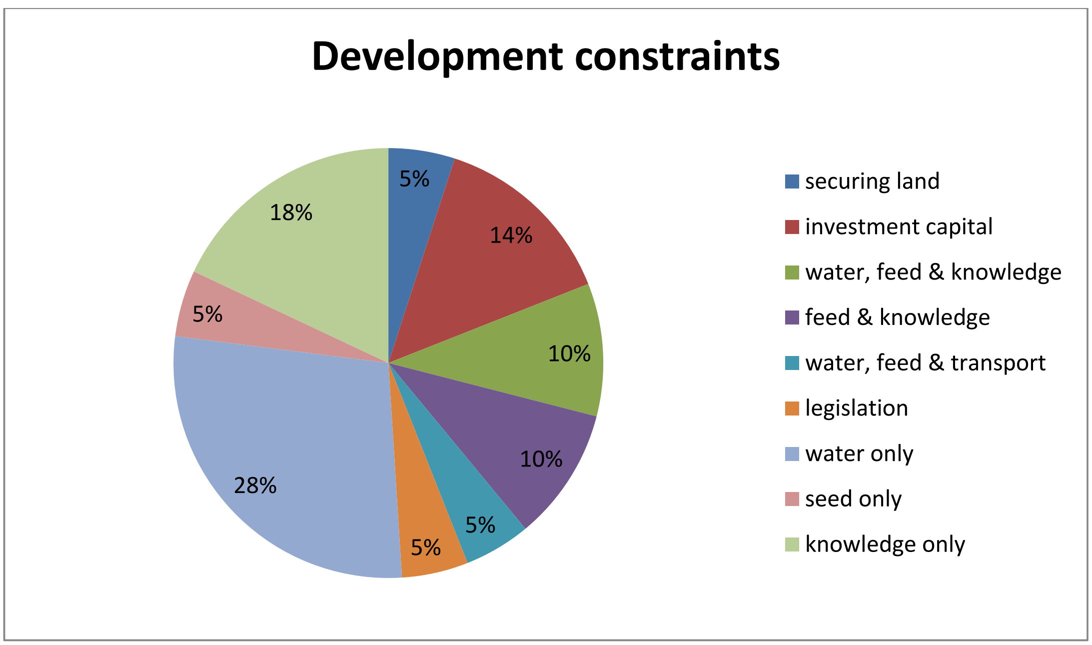

Figure 6.7. Main constraints to aquaculture's development and growth.

"Aquaculture is regarded as a high-risk agricultural investment by most commercial banks" (Miyata & Sawada, 2006). As a result, there is lack of competitive credit financing packages for potential farmers or existing farmers who want to expand their operations. Many of the successful community-based fish farms were financed through government and private grants as well as loans from farm owners and individual contributions by the project members (Rouhani & Britz, 2004). A co-operative for small-scale trout farmers in the Western Cape province, has taken the initiative to negotiate finance packages with financial institutions. It is envisaged that the willingness to fund and the commitment of financial institutions will be more forthcoming in future provided that aquaculture's track record as a viable commercial sector continues to improve and environmental sustainability is maintained (Salie, 2011).

With equal frequencies (27% each) the two largest groups were those respondents that stated that their biggest marketing constraint was competition generated by imports of aquaculture products while the other stated that they experienced no significant challenge or problem pertaining to their marketing. The "no problem" answer was evident among producers who seemed confident that they could make more money from aquaculture even with increased product to the market from other suppliers. Figure 6.8 indicate the main marketing constraints.

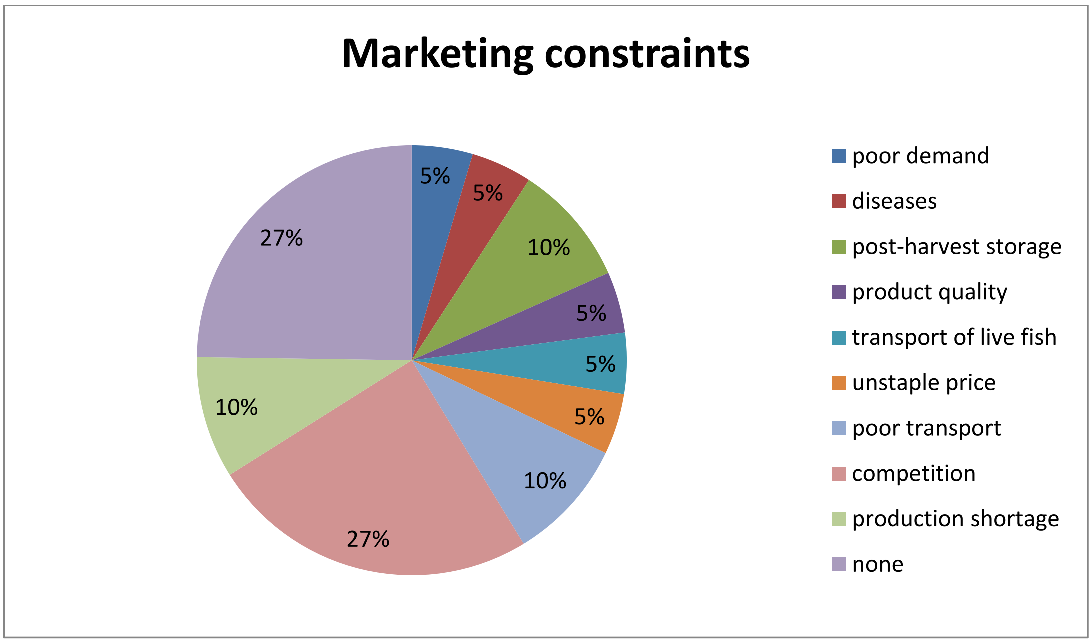

Figure 6.8. Main marketing constraints experienced by the farmers.

Competition to fish farmers in the WCP are provided by other local and global producers. There is a current import duty of 25% on trout and salmon, which is under review. It includes potential for rebates for importers of these products (ITAC, 2008). According to a few respondents, the import duties were not stringent enough and it presented an unfair competitive advantage to importing agents. Furthermore, the competition from other local producers was a result of the lack of co-operation among themselves. Marketing research and sourcing are fragmented and individual farmers determine pricing policies independently. Van Brakel & Ross (2011) described the negative impact of market fragmentation on growth and development of the aquaculture industry and related the associated reduction in growth. Other marketing problems experienced were stated as being low demand for especially freshwater fish beside trout (i.e. tilapia and catfish), insufficient disease control and regulation, maintenance of product quality and unstable prices in the market. Most respondents felt that the industry has a potential to grow, if an efficient institutional structure could be put in place. Other constraints to the development of aquaculture in South Africa were provided by the farmers and included:

- Lack of government support for promotion and awareness of aquaculture.
- Insufficient market research to determine requirement and preference.
- Limited diversity in candidate species for farming.
- Insufficient production levels to negotiate market shares in established channels.
- Lack of appropriate disease management (no dedicated aquaculture veterinary services).
- Individualism and paternalism (lack of co-operative strategies).
- Expensive post-harvest storage facilities and high freight costs.
- Legislation that prevents exotic species farming.
- Bottle-necking in trout industry processing caused by seasonal harvesting of all the fish in a short period of time.
- Insufficient quality seed material.
- Limiting growth factors for aquaculture development such as varying seasonal climate where climatic conditions are suboptimal for both warm- and cold water species.

It was important to establish where fish is sold, in order to know what the pulling or pushing forces were for consumers to these points of sales. A comprehensive majority of 80% (Fig. 6.9) were selling fish from their farms. A small component of this was actually real farm gate sales where the general local populace buy fish mainly for their own consumption. The main contingents within these sales were wholesalers and processors who send transport to collect fish from the farms. The scenario proved to be convenient for most producers.

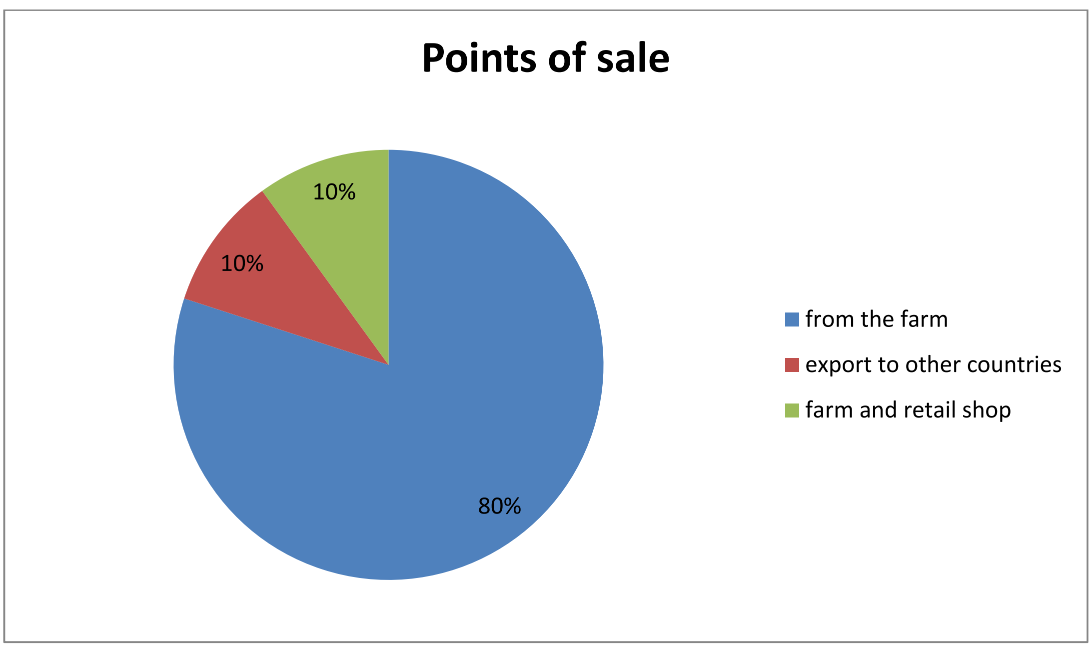

Figure 6.9. The points of sale for aquaculture products.

In such cases, all transactions would be done on the farm and usually it was the processing companies who approach farmers to buy their product. In recent times, producers formed associations which would negotiate delivery prices on behalf of themselves. Some trout farmers had outlets on their farms where smaller quantities of a range of products were sold, *inter alia,* fresh, frozen, salted and smoked. The producers that traded produce from their own farms mainly targeted niche markets. Examples of such species were trout, marron, water hawthorn and crocodiles. For these producers a lot of capital is invested in developing their supply chain networks and the farmers are responsible for all aspects of the supply chain. This arrangement can become expensive for the transaction costs were generally higher for individual marketing compared with collective marketing (Deacon, 2012).

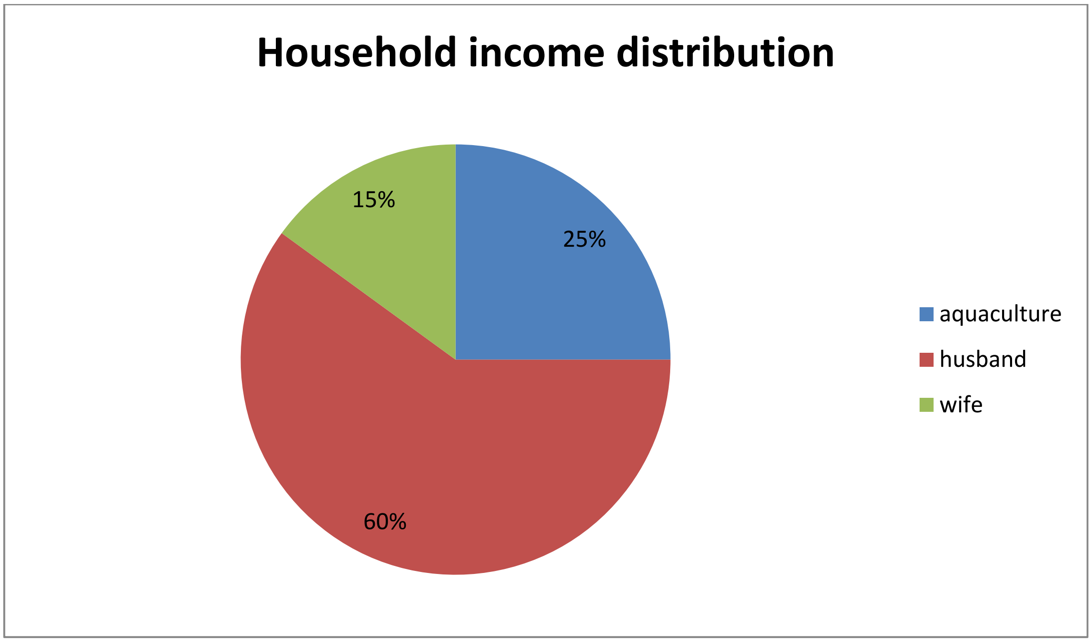

Figure 6.10. Household income contribution of a typical small-scale netcage rainbow trout farming operation.

The percentage household contribution of a typical fish farming operation in cages in irrigation dams is indicated in Figure 6.10. The household income distribution of a fish farming operation in an irrigation dam has indicated that approximately 25% of the income was annually derived from aquaculture. The husband is usually the permanent worker and wife the seasonal worker on commercial land-based crop farms in the WCP (Theron & Doorns, 2012). The husband's contribution from farm work earnings is approximately 60% to household income while the wife contributes approximately 15%. Male workers were still the dominant permanent workforce on farms in South Africa (Walters, 2012). The associated gender dynamics where males are favoured for jobs further limit opportunities to the women on farms. Belton et al, (2012) found in their study of household income in relation to aquaculture that more than 75% of household had an improvement in their income where aquaculture was practised. Therefore, it is likely that an addition of 25% to household income as encountered in the study, could contribute significantly to the wealth status of farmworkers.

6.4 Conclusion

This survey was intended to investigate and describe the role and function of aquaculture amongst farming communities. Aquaculture is shadowed by capture fisheries and is relatively unknown to the wider public. Development of aquaculture in South Africa has mainly been driven by commercial interest to serve an export market, provide quality products to the hospitality industry and ecotourism and as a retail product to higher income supermarket chains. Fish can be processed into a wide selection of products. Rainbow trout was the most prominent species featuring in these markets. Improvement in its production and range of products has increased the economic value (Feidi, 2004). This presented a wide selection of products to consumers and increased its shelf space in many retail outlets. There is a growing realisation within the aquaculture-, academia- and government sectors to diversify candidate species for production as well as the products in the value chain. This approach will provide adaption of the sector to suit the different ecological niches, farming systems and existing and emerging markets.

One of the objectives of developing aquaculture is to encourage sector participation and contribute to food security and poverty alleviation amongst a growing low-income populace. In order for aquaculture to make a major impact towards this objective in South Africa, there need to be a conscious move to develop species that could be mass produced and still be affordable at the end of the marketing chain for this consumer group. Species with such potential are tilapia, catfish and common carp. The national aquaculture strategic framework indicated that aquaculture in South Africa and its development thinking is not oriented towards this objective. The second crucial issue under this objective is that of land and water. Farming communities residing on farms appear to have a better chance of leasing or being allowed to use land (and water) owned by their employers. In some cases, municipalities own land that is not being used and have made such land available to communities for aquaculture activities. For most communities in access to water resources remains a contentious issue. South Africa is generally a water-scarce country, with future plans seriously looking at cross boundary import transfers of water from neighbouring countries. In the Western Cape, water saving measures is a common feature especially in years of poor rains. Shortage of water could therefore have a negative impact on the development of aquaculture, both nationally and in the Western Cape in particular.

There was large scale scepticism of consumers about aquaculture and was driven mainly by ignorance or mis-information about its products and its potential. This was clearly echoed by the producers that were interviewed. It remains an area that requires strategies for promotion and awareness. Effective promotion is an important building block to developing a sector (Edwards, 2009). What is clear though is that the farmed trout seems to be thriving as a candidate species farmed in cages in irrigation dams; the visible success serves as motivation to aspirant aquaculturists.

Aquaculture farmers were optimistic about the future of the sector in South Africa and they acknowledged that the industry was still in its infancy but that the industry has the potential to develop and sustain a diversity of markets. At the moment, the government is placing more emphasis on the preservation of biodiversity and the tendency has more and more been to promote re-circulation systems to limit “environmental pollution” of natural systems that can result from aquaculture. There is a need for a paradigm shift towards finding a balanced approach between development and conservation so that the tangible benefis aquaculture can bring can be unlocked.

Strategies were required to improve the knowledge base on aquaculture. The WCP is one of the leading provinces in the country in terms of promoting aquaculture through applied research and project implementation. It is home to Stellenbosch University where under- and postgraduate aquaculture curricula are presented. Further education and training could go a long way in promoting the understanding and dynamics of aquaculture. Although the industry exists within a free market economy, the lack of co-operative strategies among producers is seen as being negative and hampering growth of the industry. Efforts should be encouraged to promote coherent production and marketing strategies for the benefit of all within the sector.

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CHAPTER 7: Synthesis

7.1. Background

Water resources are a precondition for the existence of human populations, and one of the most important raw materials for our economic activity and welfare. Water is increasingly being seen as a limited resource and greater attention is being focused on priorities with regard to its allocation and management. Increasing drought affecting Africa, the problems of flood control and water quality in South-east Asia, and the impacts of development on coastal and inland freshwater resources in Latin America, all point to the particular and vital importance of water resource management in developing countries. The growth of the South African population and the pressing demand from a myriad of users intensify the challenge associated with proving sufficient water for rural, urban and industrial demands, as well as agricultural needs and to meet food production requirements. However, available water resources are increasingly being threatened by pollution from point and non-point sources which could reduce the quality and threaten the overall efficient usage. Due to the increasing demands made on existing water resources, the productivity needs to be optimised by means of controlled and limited eutrophication. Integrating aquaculture into irrigation reservoirs is promoted as a non-irrigation benefit. <u>Farming systems have been successful in incorporating multiple water use for irrigation and aquaculture into the wider context of planning, development and management of water bodies</u>. Thus, aquaculture in such water storage systems can provide opportunities to extend the potential for these forms of integration and increase the value of water use. In order to consider the utility gained from South Africa’s existing water resources, it is important that the relevant ecosystems be thoroughly investigated and that there be consultation in order to present an environmentally sustainable, socially acceptable and commercially viable partnership. Not only will this prevent conflict between potential water users but it will also allow insight into where and in which manner diversified farming options can be expanded in the future. Aquaculture is a user and not a consumer of water and should not infringe on water quantity requirements for agriculture and other anthropogenic users. However, there might be potential conflict in the demand for water space in a catchment. The overarching benefit of aquaculture to rural and peri-urban livelihoods accentuates the motivation to exploit aquaculture in the water storage networks of South Africa. Aquaculture can improve the efficiency of water use within the farm and can even improve integrated land- and water-based crop production. Most forms of waste are regarded as a resource out of place. This can have deteriorating effects on the water ecology when mismanaged. However, wastes from fish culture, especially the nutrient rich water and sediments, can also be conveniently used for the irrigation of land-based crop production and in aquaponic systems. They can further enhance wetland and riparian regeneration and ecological functioning, thus providing a habitat for plant and animal recruitment. The research project is a continuation of other research that monitored and evaluated the impact of aquaculture on the water quality of irrigation dams.

7.2. Description and analysis of water quality and production parameters

The focus of the study was on evaluating the impact of rainbow trout (*Oncorhynchus mykiss*) aquaculture on the water quality of irrigation dams. It had been determined that these dams were fit-for-use for farming high value trout destined for the higher income retail market. In order to provide sustainability to the aquaculture-agriculture integrated farming system, it was important to explore the dynamics of such a system had to be explored. Whilst fish farming is dependent on the water quality, the commercial land-based crop farmer has to recognize the value aquaculture adds to the productivity of the water resource. The number of irrigation dams has increased significantly over the last couple of decades, but aquaculture in these systems has not achieved parallel growth. Thus, this situation, together with the moderate agro-climatic conditions of the Western Cape province, necessitates the investigation of this opportunity.

The rationale is that any form of intensive agriculture, including aquaculture, will have some level of environmental impact. In aquaculture, animals are farmed under high stocking densities and fed high volumes of artificial rations. Waste production is a byproduct of fish farming. It cannot be totally eliminated because fish cannot assimilate all the feed they consume and part of the feed will remain uneaten. The wasted part can be as high as one-third of the feed input. This is the nature of most aquaculture enterprises which are driven to maximize profits and optimize feasibility. However, the future success of the operation is threatened if farmers cannot foresee long term environmental sustainability and neglect managing water ecology within target water quality parameters.

The results of research indicated that dissolved oxygen, total ammonia nitrogen and nitrate-nitrogen did not differ significantly between fish farming and non-fish farming sites. It further indicated that total suspended solids, Secchi disc reading, nitrite-nitrogen and phosphorus associated with fish farming, have been impacted through an increase in concentrations. The estimation of waste output based on fish feed for rainbow trout suggested that concentrations of ammonia and of dissolved and particulate phosphorus were not completely reflective of waste loading from cage culture. The most important non-point sources of nutrient export to receiving waters were agricultural activities. The role and function of aquaculture in the nutrient budget of farm dams were emphasized. Enrichment via the application of fertilizers and pesticides to the crops and soils could lead to eutrophication of dams, irrespective of whether aquaculture was practised or not.

The analysis of variance between water quality parameters indicated that differences in bottom and surface samples and as well as site location is more important than whether there was fish farming or not. The difference in bottom and surface samples is directly linked to the ecological status of the sediment, which serves as a nutrient sinks. In monomictic dams in Mediterranean areas, mixing occurs during the winter turnover phase. Nutrients were released due to surface and bottom water mixing, brought about by torrential rains and wind turbulence. Thus, the organic state of the sediment and bottom waters is a function of the nutrient loading over time, irrespective whether the point source was fish farming or past agricultural activities. Therefore, it can be postulated that the initial selection of site is very important in order to sustain trout farming.

Phytoplankton abundance was directly associated to the availability of nutrients, specifically phosphorous and nitrogen. The occurrence and biomass distribution fluctuated with dam water levels and nutrient concentrations. The dynamics of prevailing phytoplankton communities are important to fish farmers for two reasons, *inter alia*, firstly, it can cause fluctuation in the dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis) and secondly, it can cause algal taint of trout flesh due to geosmin producing species. Fluctuating oxygen levels as well as tainted flesh are detrimental to successful trout farming. It is crucial for farmers to be able to anticipate when algal blooms are likely to occur in order to implement measures to avoid crisis management. One way of achieving this is to monitor the nutrient levels regularly.

The analysis of the production data indicated that there was not a direct link between water quality and yield. The fish yields of farms were associated with the quality of fingerlings stocked in the net cages and the FCR obtained. Through this analysis the importance of management to secure sustainable production was accentuated. Irrigation dams can play a role in providing water bodies for floating net cage farming systems. There is a case to promote integrated aquaculture-agriculture farming through robust site selection, supported by hands-on farm management. This approach will ensure that commercial plant crop farmers' irrigation regime and yield quality will not be negatively affected.

7.3. Evaluation of land-use changes in catchment ecosystems

Catchments are characterized by multiple uses of water and land resources. Physical space is required for agriculture and other anthropogenic activities such as housing and industries. In general commercial land-based crop farmers could not provide accurate information on water extraction and diversion on the farm. Much of the extraction occurred on demand or *ad hoc* as the situation presented itself, than according to routine schedule. The data collected on water utilization on farms were inadequate to make a detailed water budget for each dam. The study revealed that these multipurpose dams had drastic declines in water level as a result of water use for irrigation. Rainbow trout culture was possible because water levels remained fairly high during the cooler part of the year when rainfall was present. However, such farm dams, if located in warmer climates of the country might not be suitable for aquaculture because of poor water quality and crowding of fish when water levels are low due to evaporation and excessive extraction for irrigation. If sufficient water levels can be maintained through the year, cage culture would be possible during periods when water levels are high enough to support net cages and allow sufficient free space for lateral flow under the cages. The dams resulted in conversion of land to water surface. In the semi-arid climate of South Africa, the formation of permanent water surfaces and small areas of wetland associated with the dams, has been beneficial to creating an ecosystem complexity and increasing biodiversity. The geographical location of the dams and associated ecology in and around enhanced a habitat for many plants and animals.

The main purpose of dams in this study was for irrigation, and nutrients from aquaculture would possibly enhance the benefits obtained from the water for this purpose. However, it has been suggested in earlier studies that increased phytoplankton production in dams as a result of aquaculture could result in clogging of irrigation systems. Aside from possibly clogging irrigation systems, eutrophication of ponds likely would not be of much of a concern where sensory perception is low. In other areas where dam water would be used for domestic purposes in addition to irrigation, eutrophication would possibly be of other concerns such as excessive turbidity, undesirable colour, and taste and odour problems.

Furthermore, the study suggests that multipurpose dams could be a valuable water supply for many rural areas in South Africa, and especially in African countries. Construction of such dams would cause changes in the landscape geometry and influences the terrestrial habitat to water surfaces relationship. Nevertheless, the inclusion of such areas in the landscape would have a beneficial effect on local ecosystems.

7.4. Mitigation to reduce organic pollution

Aquaculture can have a negative effect on the environment and can influence the functioning of freshwater ecosystem functioning. In addition, fish farm management has to take responsibility for the planning and implementing of mitigation measures to reduce organic pollution and achieve sustainable aquaculture practices. <u>Employing appropriate mitigation can reduce aquaculture's impact on the ecosystem and therefore the rationale is that any measure that reduces pollution improves the overall ecologic status of the water body</u>.

In order to facilitate sustainable aquaculture practices for small-scale community-based fish farming, procedures have been written to guide farmers. The challenge is to make these accessible and comprehendible at farming level. Education and training systems are important to ensure success in aquaculture livelihood enterprises and it is therefore proposed that aquaculture cirricula should be incorporated at secondary and tertiary institutions. As feed is responsible for most of the environmental impacts, it was confirmed that FCR improvement had a positive impact on all the environmental indicators. The mean FCR for fish farmers was 1.96 ± 1.15. Farmers were using juvenile trout of about 0.2 kg and sold fish to the market at approximately 1.2 kg. Thus the weight gain was 1 kg. Farmer were stocking 6000 fish and using on average 11760 kg of feed for the production season. If farmers could reduce/improve their FCR by 0.1 (i.e. from 1.96:1 to 1.86:1) this would translate into a saving of 600 kg of feed (5%) or 100 kg per ton of fish produced. The estimated waste output from rainbow trout cage farms per ton of fish produced was given as total solids of faecal and feed origin (236.0 kg), solid nitrogen (12.8 kg), solid phosphorous (5.3 kg), dissolved nitrogen (41.3 kg) and dissolved phosphorous (3.4 kg) respectively. <u>Thus a 0.1 decrease in the FCR would result in 5% less nutrient loading</u>.

The guar-gum based binders did not make a significant improvement in the water stability of the feed and the faecal quality for tilapia (*Oreochromis mossambicus*). The reason could be that tilapia has the capacity to digest non-starch polysaccharides and therefore guar-gum based binders did not present a good solution for stabilizing faecal matter. However, guar-gum binders did improve the water stability and faecal quality in the case of rainbow trout diets. Demand feeders (self-feeders) were used to give fish access to feed when triggered on demand. This ensures that fish ate only when hungry and minimum quantities were wasted. <u>Farmers did not benefit from such mechanical feeders as they were activated by wave and wind action to deliver feed at times when fish appetite was low</u>. This resulted in feed waste.

Heavy wind storms and wave actions made it difficult to implement and monitor the floating garden system. For the lettuce to survive in water-based agriculture, the dam had to provide growth conditions and nutrient quality similar to that found in land-based agriculture. The first goal was achieved in that a practical and economical floating garden was constructed. The second goal namely proving whether or not plants could survive and grow was also achieved. The growth for lettuce was slow due to harsh weather conditions. The study achieved growth in nine weeks very similar to what commercial farmers would achieve in three weeks in conventional hydroponic systems. For a floating garden in association with small-scale cage culture to be successful, it would require 6540 lettuces to 6000 fish to limit the accumulation of residual nutrients in a fish farming system.

7.5. Role and function of freshwater aquaculture

It was intended that the study should investigate and describe the role and function of aquaculture amongst farming communities. Information gathered during interviews showed that aquaculture remains dwarfed by capture fisheries and is relatively unknown to the wider public. Development of aquaculture has mainly been driven by commercial interest to serve an export market, provide quality products to the hospitality industry and ecotourism and as a retail product to higher income supermarket chains. Rainbow trout is the most prominent species featuring in these markets. Fish can be processed into a wide selection of products to increase its economic value. There is growing realisation though within the farming community, government and research of the need institutions to diversify the aquaculture species and product portfolio in order suit the different ecological systems, household needs, farming systems and markets.

One of the objectives of developing aquaculture is to encourage sector participation and contribute to food security and poverty alleviation amongst a growing low-income populace. Fisheries and aquaculture provide a crucial investment to the world's well-being and prosperity and contribute to the livelihoods of millions of men and women. In order for aquaculture to make a major impact towards this objective in South Africa, there need to be a conscious move to develop species that could be mass produced and still be affordable at the end of marketing chain for this consumer group. Species with such potential are tilapia, catfish and common carp. The national aquaculture strategic framework indicated that aquaculture in South Africa and its development thinking is not oriented towards this objective. The second crucial issue under this objective is that of land and water. Farming communities residing on farms appear to have a better chance of leasing or being allowed to use land (and water) owned by their employers. In some cases, municipalities own land that is not being used and have made such land available to communities for aquaculture activities. For most communities access to water resources remains a contentious issue. South Africa is generally a water short country, with future plans seriously looking at cross boundary import transfers of water from neighbouring countries. In the Western Cape, water saving measures is a common feature especially in seasons of poor rain like the last two. Shortage of water could therefore have a negative impact on the development of aquaculture, both nationally and in the Western Cape in particular.

During the interviews the producers expressed that there was large scale scepticism about aquaculture among consumers, but explained that the perception is driven by ignorance or mis-information about aquaculture, its products and its potential. This was clearly echoed by the producers that were interviewed. It remains an area that would need thorough investigation for promotion and awareness is important building blocks for developing a sector. What is clear though is that the farmed trout seems to be thriving as a candidate species farmed in cages in irrigation dams. Aquaculture farmers were optimistic about the future of the sector in South Africa and they acknowledged that the industry was still in its infancy but that the industry has the potential develop to sustain a diversity of markets. At the moment, the government is placing more emphasis on the preservation of biodiversity and the tendency has more and more been to promote re-circulation systems to limit "environmental pollution" of natural systems that can result from aquaculture.

Strategies were required to improve the knowledge base on aquaculture. The Western Cape province in South Africa is one of the leading provinces in the country in terms of promoting aquaculture through applied research and project implementation. It is home to Stellenbosch University where under- and postgraduate curricula are presented. Further education and training could go a long way in promoting the understanding and dynamics of aquaculture. Although the industry exists within a free market economy, the lack of co-operative strategies among producers is seen as being negative and hampering growth of the industry. Efforts should be encouraged to promote coherent production and marketing strategies for the benefit of all within the sector.

7.6 Research questions which were structured around the research, and answers

a. What was the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?

Small water bodies are dynamic structures with erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish- and land-based crops.

b. *What was the effect of fish farming on parameters most likely to be influenced by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most likely not to be influenced by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness)?*

The concentration of the parameters most likely not to be influenced by fish farming (depth, temperature, pH, TDS, Na, K, Ca, Mg, Fe, Cl, CO_3, HCO_3, Mn, B, Cu, Zn, Al, SO_4, alkalinity and hardness) indicated concentrations probably affected by site characteristics such as underlying geology, pollution levels, surrounding vegetation and regional prevailing climate in terms of temperature and rainfall. Soils in the WCP are mainly from weathered Table Mountain Sandstones and shales from the Malmesbury Group. The Mediterranean climate of the WCP provides winter rainfall and subsequently diluted waters, whereas in summer higher temperatures lead to increased evaporation and concentrated waters. Thus, major ions in the water fluctuate according to the changing weather patterns.

The concentrations of the parameters most likely to be influenced by fish farming (Secchi disk, DO, P, TAN, NO_3-N, NO_2-N, and TSS) can be influenced by fish farming activities. There can be a primary influence where organic particles emanating from excess feeds and faeces are suspended in the water column, changing the TSS concentration and consequently the water transparency observed in the Secchi disk reading. Secondarily, nitrogenous compounds are released into the water environment through nitrification by aerobic micro-organisms (Nitrosomonas and Nitrobacter spp), as well as through denitrification. Dissolved oxygen levels are influenced by the rate of photosynthesis and the decomposition of organic material. Phosphorous is mainly released from the feed. The ratio of fish farming to non-fish farming ranges from 0.8 (TAN) to 2.06 (P). These ratios are relatively low and are indicative of good water resource management by both fish- and crop farmers.

c. To what extent do surface and bottom water of the reservoir differ?

Irrigation dams generally indicated no levels of stratification, thus showing adequate mixing of surface and bottom waters. This can be ascribed to relatively shallow dams with an average depth of 7 m. Dams with low Secchi disk readings (transparency) also showed lower oxygen levels in bottom strata. The following parameters, DO, pH, Fe, P, PO_4, TAN, NO_2, TSS, TDS and alkalinity, indicated statistical significance between surface and bottom. The following parameters Na, K, Ca, Cl, SO_4, B, Mn, Cu, Zn, NO_3, AL and hardness, did not indicate statistical significance between surface and bottom.

d. What was the nature of phytoplankton occurrence and diversity in irrigation dams?

The occurrence and phytoplankton biomass distribution fluctuated with dam water levels and nutrient concentrations. The prevailing phytoplankton communities are important to fish farmers for two reasons, namely: 1. They have an influence on dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis), and 2. There may be an algal taint of trout flesh due to geosmin-producing species. The anticipation of the impact of existing phytoplankton on the quality of trout production requires attention. It was evident that phytoplankton biomass and diversity can be controlled by ensuring sub-optimal conditions through reducing nutrient input. The frequency of occurrence indicated that the Group Chlorophyta (including genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, etc) occurred most often (371) with Chrysophyta (including genera, *Dinobryon, Mallomonas, Synura*, etc) occurring least often (34). The type of genus as well as the prevailing season had a significant influence on the occurrence of phytoplankton ($p<0.05$). However, the geographical location of the research site had no significant influence on the occurrence of phytoplankton ($p>0.05$).

e. What is theinfluence of historical commercial agriculture on farm dam dynamics?

The general water quality indicated that irrigation dam water quality is relatively well-managed by the commercial crop farmers in the WCP. However, in studies elsewhere in South Africa, e.g. KwaZulu Natal and Mpumalanga, dams in the area were classified as eutrophic and in certain cases hypertrophic. Thus, the concern remains that our water resources as a whole lack appropriate management and compliance with better management practices. Aquaculture has been proven to provide real benefits to rural and urban communities and co-existence and integrated aquaculture-agriculture will only prosper when both primary and secondary users of irrigation dams apply practices to sustain good water.

f. Can the negative and positive impacts of aquaculture on irrigation reservoirs and water use be identified?

It was found that aquaculture in irrigation dams has a negative impact on the water quality due to organic enrichment via excess feeds and faeces. Some farmers also reported clogging of irrigation systems. Positive impacts were identified as an increase in diversity in aquatic plant and animal occurrence. The post-fish farm zone (in the water course below the fish farming dam) showed the establishment of additional wetland plant species. An increase in birdlife, rodents and small mammals was also observed in and around dams where fish farming activities took place.

g. What is the relationship between fish production data and water quality parameters?

Fish production output (total kg fish yield) from farms was closely associated with the quality of juveniles/fingerlings for stocking. The other important parameter determining harvest quality was the farm's

FCR. Thus, management of the operation is considered to be more important than the prevailing water quality. The water quality parameters, including, DO, pH, TAN, PO_4 and Secchi disk did not influence the yield of farms.

h. What are the land-use changes which could occur in catchments where there is fish farming and what interactions could be described among the changes?

Aquaculture is conducted in irrigation dams. The land-use is primarily affected by the turnover of terrestrial arable land into water storage bodies. The below-dam ecology has also changed and adapted to flow patterns resulting from dam overflows. Light industry and agriculture around the dam area are more aware of potential pollution from their operations and are generally more cognisant of harming the aquaculture operations.

i. Does freshwater aquaculture add value to livelihood strategies of rural and peri-urban farming communities?

Peri-urban and rural communities are in dire need of economic activity to present income and livelihood opportunities. These communities support aquaculture in their areas for it has been found to lead to job creation.

j. Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?

Mechanical mitigation in the form of a demand feeder were found to be impractical or too costly to be used on irrigation dam cage culture of fish. Extraction of nutrient from dams via floating gardens has been found to have potential to reduce organic pollution arising from feed, faeces and surrounding land. Irrigation dams provide large quantities of water surface areas to be used for floating gardens.

k. Can eutrophied water bodies be used for plant production?

Nutrient rich water bodies can be considered as hydroponic systems e.g. floating gardens on farm dams. In our investigation it was found that certain vegetables can be successfully grown on floats incorporated next to net cages for fish.

l. What are the challenges associated with technology and knowledge transfers?

To achieve technology transfer, we need to understand the following elements:

a. What information is available?
b. In which manner is the information accessed?
c. How is the obtained information used?
d. What constraints do fish farmers experience when accessing information?
e. What processes influence priority in information selection for implementation?
f. How much of farmer knowledge is based on existing or new information?
g. What is the cost-benefit of information access and dissemination?
h. How are our farmers managing the mass influx of information?

Thorough understandings of these elements will provide a measure to the success of technology transfer.

m. What is the public's understanding of aquaculture?

The aquaculturists communicated that the broader public's understanding of aquaculture in South Africa is limited and mainly associated with large-scale operations with shrimp and salmon. The public needs to be made aware of the potential of aquaculture to contribute to food security and socio-economic development. Aquaculture can provide individuals and communities the opportunity to run a sustainable enterprise and to participate in the aquaculture sector.

n. What are the key issues of consideration by regulators and decision makers?

Integrated aquaculture-agriculture systems provide an alternative strategy to optimise utilisation of South Africa's water resources. Our existing resources are continuously under pressure from the increasing demand from the public and industrial sectors. National government should be encouraged to:

a. Promote integrated farming systems in irrigation dams through incentives to farm owners
b. Develop strategies to optimise associated water resource management requirements
c. Regulate effluent discharge to reduce ecosystem pollution and ecological integrity
d. Facilitate captive markets for fish and crops
e. Encourage secondary and tertiary institutions to include aquaculture in their cirricula
f. Support directed research programmes on farm dams.

One of the objectives of developing aquaculture is to encourage sector participation and contribute to food security and poverty alleviation amongst a growing low-income populace. <u>Fisheries and aquaculture provide a crucial investment in the world's well-being and prosperity and contribute to the livelihoods of millions of men and women</u>. In order for aquaculture to make a major impact on prosperity in South Africa, there needs to be a conscious move to develop species that can be mass produced and still be affordable at the end of marketing chain. Species with this potential are tilapia, catfish and common carp. The national aquaculture strategic framework indicates that aquaculture in South Africa and its development thinking is not oriented towards this objective. The second crucial issue that of land and water. Farming communities residing on farms appear to have a better chance of leasing or being allowed to use land (and water) owned by their employers. In some cases, municipalities own land that is not being used and have made such land available to communities for aquaculture activities. For most communities access to water resources remains a contentious issue. South Africa is generally a water short country, making serious plans to import water from neighbouring countries. In the Western Cape, water saving measures are common especially in seasons of poor rainfall like the last two. Shortage of water could therefore have a negative impact on the development of aquaculture, both nationally and in the Western Cape in particular.

There was large scale scepticism about aquaculture driven by ignorance or ill-information about aquaculture, its products and its potential. This was clearly echoed by the producers that were interviewed. Aquaculture remains an area in need of investigation. Promotion and awareness-raising are important building blocks when developing a sector. What is clear though is that the farmed trout seems to be thriving as a candidate species farmed in cages in irrigation dams. <u>Aquaculture farmers are optimistic about the future of the sector in South Africa and they acknowledge that the industry is still in its infancy but that the industry has the potential to sustain a diversity of markets</u>. At the moment, the government is placing more emphasis on the

preservation of biodiversity and the tendency is to promote re-circulation systems to limit the “environmental pollution” of natural systems that can result from aquaculture.
Strategies are required to improve the knowledge base on aquaculture. The WCP in South Africa is one of the leading provinces in the country in terms of promoting aquaculture through applied research and project implementation. It is home to Stellenbosch University where under- and postgraduate cirricula in aquaculture are presented. Further education and training could go a long way towards promoting the understanding and dynamics of aquaculture. Although the industry exists within a free market economy, the lack of co-operative strategies among producers is seen as being negative and hampering the growth of the industry. Efforts to promote coherent production and marketing strategies for the benefit of all within the sector should be encouraged.

7.7. Recommendations and future research

Irrigation dams in the Western Cape province have a history of enrichment through external sources supplying water such as agricultural runoff (fertilisers and pesticides), catchment runoff (leaf litter and organic debris) and stormwater effluent (grey and black water). The incorporation of aquaculture into such dams adds extra nutrients to the water column and sediment even if they are limited in concentration. Therefore future research needs to focus on:

- The prevention and minimisation of pollution deriving from aquaculture through improved management. This can be achieved by optimising technology transfer.
- Monitoring catchment as a continuum with all the external factors affecting the ecology of farm dams. This can be achieved through qualifying the point source and presenting guidelines to minimise it.
- The sediment processes and dynamics need to be understood. This can be achieved through incorporating monitoring programmes on the ecological status of the bottom waters of the dams.

Furthermore, this research project is one of a series of research studies that investigated the interaction of floating net cage fish farming and irrigation farm dams over the last decade. It is proposed to consolidate the research protocol and monitor and evaluate the impact of gained knowledge and technology advancements at farmer level. Of particular interest would be:

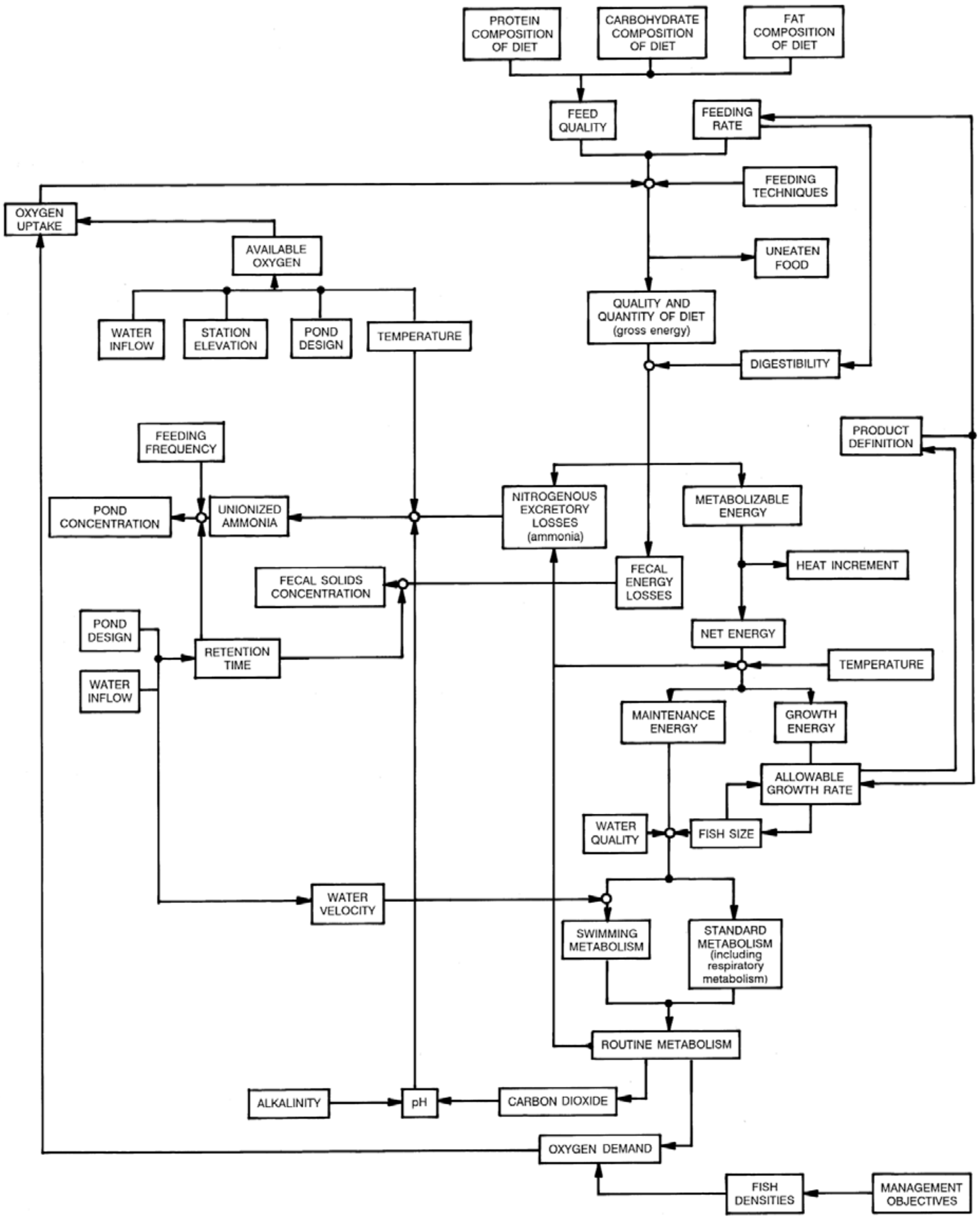
- Accessibility to knowledge,
- Level of comprehension and practicality,
- Cost-effectiveness of adapting and implementation,
- Indication of cost-benefit to the farmer,
- Effectiveness of knowledge and technology application on production performance.

The outcome of such an approach will provide an agenda and new evidence in order to set the benchmarks for forthcoming aquaculture research and development.

APPENDICES

APPENDIX 1

Interaction of biotic and abiotic factors in an aquaculture system (Klontz, 1991)



APPENDIX 2

Research site information, including production years, geography, hydrology and land-use.

Site no	Site name	2008	2009	2010	2011	Coordinates	Mean depth (m)	Elevation (m)	Water supply	Geology	Surrounding land use	Resource utilisation
1	Nietvoorbij	X	X			33º55'4.02''S 18º51'47.46''E	5.0	150	Plankenbrug river, runoff	granite, shale	vineyards	aquaculture, irrigation
2	Damn Dam					33º53'52.55''S 19º1'8.77''E	12.0	240	runoff	granite, sandstone	vineyards, orchards	aquaculture, irrigation
3	Ginaskloof	X				33º53'42.17''S 19º0'57.32''E	6.6	231	runoff	granite, sandstone	vineyards, orchards	aquaculture, irrigation
4	Plaisir de Merle	X	X			33º51'6.21''S 18º57'4.95''E	6.5	194	runoff, pump	shale, sandstone	vineyards, orchards	aquaculture, irrigation
5	Kleinplaasdam	X	X			33º58'31.68''S 18º56'38.36''E	6.7	274	runoff, pump	granite, sandstone	vegetation, plantation	aquaculture, drinking
6	Rondawel	X				33º54'27.0''S 18º53'2.58''E	4.4	211	upper dam, runoff	granite, shale	vineyards, fruit orchards	aquaculture, irrigation
7	Buzzardkloof					33º53'19.22''S 18º53'40.35''E	9.7	309	runoff	granite, shale	vineyards, orchards	irrigation
8	Rachelsfontein		X	X		33º52'18.14''S 18º57'29.97''E	8.4	231	runoff	sandstone, shale	vineyards, orchards	aquaculture, irrigation
9	Mountain Vineyards		X	X		33º52'20.07''S 18º57'20.09''E	10.5	248	runoff, pump	sandstone, shale	vineyards, orchards	aquaculture, irrigation
10	Ezelfontein	X	X			33º24'14.70''S 19º26'33.57''E	7.1	548	runoff	sandstone	orchards	aquaculture, irrigation
11	Rocklands		X			33º04'55.42''S 19º17'53.68''E	9.5	1124	3 mountain streams	sandstone	orchards, vegetables	aquaculture, irrigation
12	Soetfontein	X	X			33º00'01.92''S 19º17'53.68''E	7.8	954	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
13	Boplaas		X			32º58'43.95''S 19º21'42.98''E	7.5	973	mountain stream	Bokkeveld shale	orchards	aquaculture, irrigation
14	Môrester		X			32º57'02.16''S 19º23'42.42''E	9.0	1086	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
15	Weltevrede/ Tweefontein.		X			32º56'17.86''S 19º23'07.99''E	6.7	1126	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
16	Toeka		X			32º59'53.21''S 19º25'10.49''E	9.4	961	mountain stream	Bokkeveld shale	orchards, vegetables	aquaculture, irrigation
17	Westland/Kolk		X			33º00'49.66''S 19º23'15.21''E	3.4	939	runoff, pump	sandstone	orchards	aquaculture, irrigation
18	Worcester	X	X			33º35'53.69''S 19º26'25.25''E	8.9	388	runoff, pump	granite, shale sandstone	natural vegetation	aquaculture, irrigation of golf course

19	Goedgeloof – old	X	X	X		33°30'24.91''S 19°11'45.84''E	7.8	260	runoff, pump	sandstone, shale	vineyards, orchards	aquaculture, irrigation
20	Goedgeloof – new	X	X	X		33°30'13.15''S 19°12'9.05''E	6.7	250	runoff,pump	sandstone, shale	vineyards, orchards	aquaculture, irrigation
21	Cape Olive		X	X		33°42'22.8''S 19°1'59.34''E	11.5	193	river, runoff	granite, shale	vineyards, olive orchards	aquaculture, irrigation
22	Theewaterskloof	X				34°2'35.03''S 19°19'37.98''E	6.6	571	runoff	granite, sandstone	orchards	aquaculture, irrigation
23	Voorhoede	X	X			34°13'14.38''S 19°29'37.72''E	6.6	399	runoff	sandstone	orchards	aquaculture, irrigation
24	Barton	X	X			33°15'40.01''S 19°10'8.17''E	5.8	259	runoff	sandstone	orchards	aquaculture, irrigation
25	Nuwejaarsrivier	X	X	X	X	34°17'34.76''S 19°4'43.00''E	5.9	394	runoff, spring	sandstone	orchards	aquaculture, irrigation
26	Boomerang	X				34°11'15.95''S 19°1'59.34''E	8.4	328	runoff	granite, sandstone	orchards	aquaculture, irrigation
27	Duiwelskloof	X				34°11'26.13''S 19°1'36.26''E	13.0	269	runoff	granite, sandstone	orchards	aquaculture, irrigation
28	Remhoogte 1	X	X			34°11'26.13''S 19°1'36.26''E	8.9	269	runoff	granite, sandstone	orchards	aquaculture, irrigation
29	Remhoogte 2	X	X			34°11'26.13''S 19°1'36.26''E	6.9	269	runoff	granite, sandstone	orchards	aquaculture, irrigation

APPENDIX 3

Production data of trout farms for 2009 with associated physico-chemical water quality parameters

Site no	Hatchery	Stocking date	Harvesting date	Production days	Total kg in	Total kg out	Avg size of fish in (g)	Avg size of fish out (g)	No fish in	No fish out	Fish losses	FCR	SGR	DO mg/L	pH	TAN mg/L	PO_4 mg/L	Secchi cm
24	L	2009/05/25	2009/10/22	150	1206	6355	201	1155	6000	5500	500	1.17	1.18	8.9	6.5	0.518	0.244	113
13	R	2009/06/12	2009/10/16	126	3430	6068	570	1130	6018	5369	649	1.87	0.55	9.4	7.1	0.183	0.018	135
21	R	2009/05/22	2009/10/19	150	1086	6100	181	1109	6000	5500	500	1.40	1.22	8.7	7.2	0.214	0.061	90
28	D	2009/06/29	2009/11/26	150	1604	4854	210	883	7638	5500	2138	1.70	0.97	10.3	7.0	0.309	0.092	163
29	D	2009/06/30	2009/11/27	150	1180	4340	241	789	4896	5500	-604	1.75	0.80	10.6	7.2	0.293	0.080	158
10	R	2009/05/20	2009/09/29	132	1200	1482	198	355	6061	4178	1883	*	0.45	9.7	7.5	0.307	*	126
20	J	2009/05/13	2009/10/07	147	708	7027	118	1197	6000	5870	130	1.33	1.60	8.8	7.2	0.183	0.024	123
19	J	2009/05/13	2009/10/06	146	708	7422	118	1212	6000	6126	-126	1.25	1.62	8.5	6.7	0.174	0.009	130
9	R	2009/06/22	2009/11/23	154	1760	6583	325	1197	5415	5500	-85	1.52	0.86	8.4	6.9	0.353	*	140
1	L	2009/06/05	2009/10/22	139	2591	3740	400	680	6478	5500	978	4.81	0.39	9.8	7.5	0.470	0.144	76
25	J	2009/05/12	2009/11/16	188	708	6769	118	1327	6000	5101	899	1.40	1.30	8.8	6.9	0.481	0.065	80
4	L	2009/06/04	2009/10/30	148	2298	6662	345	1211	6661	5500	1161	1.66	0.86	9.4	7.1	0.185	0.042	98
8	R	2009/06/24	2009/11/27	156	1256	5568	200	1012	6280	5500	780	1.70	1.05	8.9	6.9	0.404	*	130
17	R	2009/06/15	2009/10/13	120	2593	3616	570	1115	4549	3243	1306	4.43	0.57	9.3	7.1	0.109	0.069	133
18	R	2009/05/19	2009/10/20	154	1188	6067	198	1045	6000	5805	195	1.43	1.09	8.2	6.8	0.155	0.087	121

* empty blocks indicate missing data

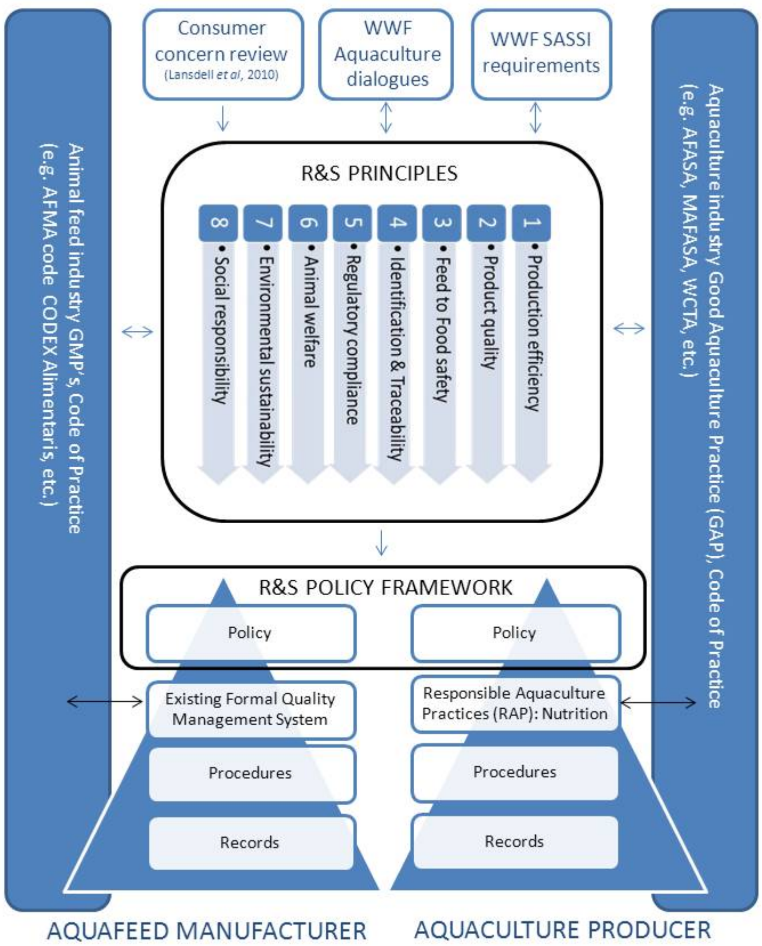
Hatchery: D = De Hoek; J = Jonkershoek; L = Lourensford; R = Remhoogte

Site no: 24 = Barton; 13 = Bo-Plaas; 21 = Cape Olive; 28 = Remhoogte 1; 29 = Remhoogte 2; 10 = Ezelfontein; 20 = Goedgeloof (new); 19 = Goedgeloof (old); 9 = Mountain Vineyards; 1 = Nietvoorbij; 25 = Nuwejaarsrivier; 4 = Plaisir de Merle; 8 = Rachelsfontein; 17 Westland/Kolk; 18 = Worcester

APPENDIX 4

Management system for responsible aquaculture nutrition (Lansdell, 2010)

SUBJECT:	Policy framework for responsible and sustainable aquaculture nutrition	FILENAME:	Framework for responsible and sustainable aquaculture nutrition.doc
REFERENCE:	Management system for Responsible Aquaculture Nutrition 2011, 1.0		Page 148 of 189
APPROVED BY:		DATE:	EDITION: 0



<u>Policy framework for Responsible and Sustainable Aquaculture Nutrition</u>

To develop, lead and operate an industry and/or organization successfully, it is necessary to manage it in a transparent, systematic and visible manner. The guidance to management offered in this framework is based on eight principles. These principles have been developed for use by role players/stakeholders in order to promote a responsible and sustainable aquaculture industry (Figure 1). These principles are integrated in the contents of the framework and are listed below:

Figure 1. Process model for responsible and sustainable aquafeed management system

The Organization (feed input supplier, aquaculture producer), in line with the principles set out in the framework, commit to responsible and sustainable aquafeed and feeding management through ideals and practises designed to promote:

- **Principle 1 - Production efficiency:**
  - Ensuring optimal use of resource,
  - Achieving optimal product output, and
  - Attaining profitable economical returns for sustainable financial input.

- **Principle 2 - Product quality:**
  - Setting, meeting and striving to continuously improve quality objectives of aquafeed and its impact on end-product quality.

- **Principle 3 - Feed to food safety:**
  - Addressing safety concerns throughout product realisation based on HACCP principles.

- **Principle 4 - Identification and Traceability:**
  - Where appropriate, identifying of aquaculture produce and aquafeed ingredients by suitable means throughout product realization,
  - Identifying product status with respect to monitoring and measurement requirements,
  - Providing traceability to source when required, and
  - Providing appropriate information for the promotion of transparency,

- **Principle 5 - Regulatory compliance:**
  - Complying with applicable local, national and/or international laws and regulations

- **Principle 6 - Animal welfare:**
  - Supporting and contributing to animal welfare in product evaluation, commercial production, and impact on wild populations.

- **Principle 7 - Environmental sustainability:**
  - Assessing and monitoring the impact of activities on the environment, and
  - Promoting practices that enhance environmental sustainability.

- **Principle 8 - Social Responsibility:**
  - Acting in a social responsible manner by
    - Adhering to relevant laws and regulations,
    - Promoting interaction with stakeholders,
    - Respecting impact on society at large,
    - Promoting fair access to natural resources, and
    - Establishing mutually beneficial relationships.

The organisation believes that excellence is a commitment to consistently procure and supply products as well as provide services that meet or exceed our customers' requirements. We are committed to comply with requirements and continually improve effectiveness of our management system and principles. The management system and principles form the basis of our total commitment to meet industry and/or organizational goals, as well as legal and/or regulatory requirements and client and market expectations in a cost effective and acceptable manner. The system outlined in this framework defines the means by which the management and staff of this organisation will constantly strive to meet objectives and to promote principles.

The organization is committed to ensure that:

- The policy is appropriate to the purpose of the organisation, to promote a responsible and sustainable industry,
- The necessary resources are available to achieve the objective,
- Staff are familiarized with the system and expected to comply with,
- The policy is supported by measurable objectives,
- The policy is reviewed for continued suitability and effectiveness.

APPENDIX 5

Examples of procedures that have been written (Lansdell, 2010).

SUBJECT: PROCEDURE FOR CALCULATING PRODUCTION PERFORMANCE OF FISH: FEED CONVERSION RATIO		FILENAME:
REFERENCE: Responsible aquafeeding Practices 2011.1		PAGE NR: Page 151 of 189
APPROVED BY:	DATE:	EDITION:

1. PURPOSE:

The purpose of the procedure is to calculate the efficiency of the animal to convert feed mass into body mass and thus estimate diet efficiency

2. SCOPE:

The procedure is applicable to grow-out managers, farm managers, researchers and general workers

3. EQUIPMENT NEEDED:

- Calculator or Excel sheet

4. PROCEDURE:

1. Feed conversion ratio (FCR) will be calculated as feed consumption (dry matter) / live weight gain after one month or a certain amount of months.

$$FCR = \frac{FI_t\ [g]}{W_t\ [g] - W_0\ [g]}$$

where:

FI	=	Feed consumption after t days [g]
W_0	=	initial weight of the fish [g]
W_t	=	final weight after t days [g]

I have read and understand the procedure		
SIGNED:	DATE:	

SUBJECT: PROCEDURE FOR THE PROCUREMENT OF AQUAFEED		FILENAME:
REFERENCE: Responsible aquafeeding practices 2011.1		PAGE NR: Page 151 of 2
APPROVED BY:	DATE:	EDITION:

1. PURPOSE

The Organization is committed to environmentally responsible practices with regard to the sourcing of aquafeed. This procedure complements the existing auditable quality management system to support the drive towards meeting international standards and best practices with regard to Aquaculture. *The Organization* recognises and acknowledges its accountability and commitment to source aquafeed for responsible and sustainable aquaculture

In addition to the principles (principles 1, 2, 3, 4, 5, 6, 7 and 8) set out in the responsible and sustainable aquaculture nutrition policy (RANP), specific objectives of this procedure are to ensure that:

- Aquafeed is sourced from responsible aquafeed manufacturers, and
- traceability to source can be verified, without compromising aquafeed quality and performance

2. SCOPE

Where relevant, this procedure applies to the:

- Farm manager
- Farm quality manager
- Aquafeed procurement manager
- Farm technical manager

Specific considerations include:

- All aquafeed processes are audited at least annually. More regular inspections of the farm and products will be carried out where deemed necessary due to risk assessment.
- The scoring of the "Procedure for sourcing aquafeed" statutory requirements and audits are monitored and reviewed regularly.
- Co-operate with aquafeed providers to ensure that all aspects of the feed safety management system are adhered to.
- Report any issues which they believe could result in feed borne illness or disease to manager
- Develop and implement appropriate management systems to ensure that all feed is safe
- Assess all risks associated with aquafeed production and introduce control measures to reduce those risks to a tolerable level.
- Ensure that all feed handlers are trained to a level of competence commensurate with their duties.
- Comply with all relevant company policies and procedures.
- Maintain all records and have these available at each facility for inspection at all times

3. EQUIPMENT NEEDED

N/A

4. PROCEDURE

The Organization undertakes to source Aquafeeds responsibly by:

- Sourcing aquafeeds from suppliers that that take the following principles into consideration (as defined in the responsible and sustainable aquaculture nutrition framework policy)

1. Production Efficiency
2. Production Quality
3. Feed to Food Safety
4. Identification and Traceability
5. Regulatory Compliance
6. Animal Welfare
7. Environmental Sustainability
8. Social Responsibility

The Organization also acknowledges the responsibility towards clients for the continuous supply of quality product to ensure sustainable aquaculture. Therefore, if aquafeed is not available from the abovementioned sources or do not comply with internal ingredient quality requirements, it will be procured from alternative sources and communicated to clients and/or relevant authorities.

I have read and understand the procedure		
SIGNED:	DATE:	
SUBJECT: PROCEDURE FOR FEEDING RAINBOW TROUT PIGMENT-ENRICHED FEEDS: BROODSTOCK		FILENAME:
REFERENCE: Responsible aquafeeding practices 2011.1		PAGE NR: Page 153 of 1
APPROVED BY:	DATE:	EDITION:

1. PURPOSE:

The aim of dietary pigmentation is to:

- Achieve the most economic pigmentation rate to pigment the whole trout population to a minimum acceptable level,
- With the least variation,
- Without incurring economic loss due to product rejection

This would have unique implications for reproductive performance of brood stock and the hatchability and survival of ova.

2. SCOPE:

The procedure is applicable to the farm manager.

3. EQUIPMENT NEEDED:

4. PROCEDURE:

- Always ensure that the feed containing pigments are stored in a cool and dry environment to protect the integrity of the sensitive pigments.
- Feed older than three months should not be used.
- Feeding rate should be applied according to the recommendations of the feed supplier.
- Feed should be used containing 40 ppm or 80 ppm pigment respectively 8 or 4 months before spawning.
- Always make sure that all fish has equal access to feeding during feeding.
- Do not fast fish during the pigmentation period.
- Do not alternate between different feed sources during the pigmentation period.

5. FURTHER CONSIDERATIONS:

- A 40ppm trout brood stock feed may typically contain:

1. A 40 ppm (500g/ton feed) astaxanthin containing product, which can be either Carophyll Pink® (DSM) or Lucantin® Pink (BASF), typically with 8% astaxanthin activity,
2. a 40 ppm (400g/ton feed) canthaxanthin containing product, which can be either Carophyll Red® (DSM) or Lucantin® Red (BASF), typically with 10% canthaxanthin activity, or
3. A 40 ppm mixed xanthophyll pigment product may consists of a combination of locally available:
   i. 20ppm (250g/ton feed) Astaxanthin containing product, which can be either Carophyll Pink® (DSM) or Lucantin® Pink (BASF), typically with 8% astaxanthin activity, and
   ii. 20ppm (200g/ton feed) Canthaxanthin containing product, which can be either Carophyll Red® (DSM) or Lucantin® Red (BASF), typically with 10% canthaxanthin activity.

- On 24 January 2003, the European Commission adopted a directive to reduce the authorized use of cantaxanthin in animal feed. The new Commission Directive (2003/7/EC) sets a maximum of 25 mg/kg for cantaxanthin in feed for salmonids instead of the 80 mg/kg previously allowed. The directive went into effect 1 December 2003.

I have read and understand the procedure	
SIGNED:	DATE:

APPENDIX 6

List of genera for seven major groups of phytoplankton. Number in brackets refers to occurrences.

Group Bacillariophyta with 20 genera; also known as Diatoms	*Amphipleura* Kützing (2) *Asterionella* Hassall (1) *Aulacoseira* Thwaites (16) *Cocconeis* Ehrenberg (1) *Craticula* Grunow (1) *Cyclotella* Kützing *ex* Brébisson (11) *Cymbella* Agardh (8) *Diadesmis* Kützing (2) *Fragilaria* Lyngbye (1) *Gomphonema* Ehrenberg (5) *Gyrosigma* Hassall (1) *Melosira* Agardh (2) *Navicula* Bory (8) *Nitzschia* Hassal (47) *Pinnularia* Ehrenberg (3) *Pleurosigma* W. Smith (2) *Rhopalodia* Müller (3) *Surirella* Turpin (1) *Synedra* Ehrenberg (12) *Tabellaria* Ehrenberg (3)
Group Chlorophyta with 23 genera; also known as Green algae	*Ankistrodesmus* Corda (17) *Ankyra* Fott (2) *Chlamydomonas* Ehrenberg (22) *Chlorella* Beijerinck (3) *Chlorogonium* Ehrenberg (17) *Closterium* Nitzsch *ex* Ralfs (29) *Coelastrum* Nageli (6) *Cosmarium* Corda *ex* Ralfs (3) *Crucigenia* Morren (10) *Crucigeniella* Lemmermann (7) *Dictyosphaerium* Nägeli (47) *Eremosphaera* DeBary (3) *Golenkinia* Chodat (4) *Lagerheimia* Chodat = *Chodatella* Lemmermann (1) *Micrasterias* Agardh *ex* Ralfs (1) *Monoraphidium* Komárková-Legnerová (48)

	Oedogonium Link (1) *Oocystis* Braun (56) *Pandorina* Bory de Saint-Vincent (13) *Pediastrum* Meyen (11) *Scenedesmus* Meyen (16) *Staurastrum* Meyen *ex* Ralfs (49) *Tetraedron* Kützing (5)
Group Chrysophyta with 2 genera; also known as Golden-brown algae	*Dinobryon* Ehrenberg (32) *Mallomonas* Perty (2)
Group Cryptophyta with 1 genus; also known as Cryptomonads	*Cryptomonas* Ehrenberg (45)
Group Cyanophyta with 5 genera; also known as Blue-green algae	*Anabaena* Bory *ex* Bornet *et* Flahault (21) *Arthrospira* Stizenberger *ex* Gomont (1) *Cylindrospermopsis* Seenayya *et* Subba Raju (6) *Lyngbya* Agardh *ex* Gomont (2) *Microcystis* Kützing *ex* Lemmermann (36)
Group Dinophyta with 3 genera; also known as Dinoflagellates	*Ceratium* Schrank (29) *Peridinium* Ehrenberg (31) *Sphaerodinium* Woloszynska (10)
Group Euglenophyta with 3 genera; also known as Euglenoids	*Euglena* Ehrenberg (2) *Phacus* Dujardin (1) *Trachelomonas* Ehrenberg (6)

APPENDIX 7

FISH PRODUCER SURVEY

Name of Interviewer: ______________________________ Date: ____________________

Household number (if applicable): ___________________

Location of farm

Village/community: ____________________________ Sub-district: ___________________________

District/State: ________________________________ Country: ______________________________

Nearest urban center: __________________________ Distance to urban center (km): ____________

Distance to main road (km): ______________

Photo reference: ______________________________

AQUACULTURE ACTIVITIES

1. Number of ponds: _______________ Total pond size (area m^2): ________________

2. Other aquaculture production systems: ____

3. Resource issues: (✔)

I own the land all / some %	All	Some (%)
I rent the land from other 3rd party:		
Family		
Government		
Just using land - squatting		

4. Purpose of farming: (✔)

Seed production for sale		Recreational	
Final consumption for sale		Household consumption	

5. How long have you farmed fish? (✔)

Less than 1 year		3 – 4 years		7 – 10 years	
1 – 2 years		5 – 6 years		Over 10 years	

6. What type of fish do you produce and in what form(s) are they sold?

Type	Specify local name	Tick all applicable (✔)						
		Live	Fresh	Smoked	Frozen	Salted	Fillets	Other
Catfish								
Tilapia								
Carp								
Ornamentals								
Others								

7. What is your normal harvesting strategy? (✔) Partial harvest ___ Complete harvest ___

8. What post-harvest storage facilities do you have? (✔)

Holding tanks for live fish		Processing facility	
Cold room / refrigeration		None	
Ambient storage			

9. How often do you sell your fish? (✔)(Note frequency)

	Daily	Weekly	Fortnightly	Monthly	Quarterly	Yearly
✔						
Frequency						

10. Who is selling your fish? (✔)

Self/family	
Cooperative	

Association / group	
Others: pls specify	

11. From where do you sell your fish (✔) Please provide some indication of % volume sold in each outlet type?

Place - outlet type	Always		Sometimes		Rarely		Never
	✔	%	✔	%	✔	%	✔
On the farm							
Market place							
Shop							
Other:							

12. Who are your main **paying** customers? (✔)

Customers	(✔)	Ranking (1 most important)
Family		
Neighbours / friends		
Other consumers		
Traders (middlemen)		
Wholesalers		
Shop owners		
Fish processors		
Restaurants / hotels		
Others:		

13. What size of fish do you normally harvest? (✔)

Size	(✔)	For how much do you sell these fish?		The prices for the same fish last year?	
		Price	Unit	Price	unit
Fingerlings					
Up to 49g					
50 – 99g					
100 – 499g					
500g – 999kg					
Over 1kg					

14. Do you feel there is a demand for more fish from your site (✔)

Yes		No		Don't know	

15. If yes, What do you regard as your constraint(s) to production (Can tick more than 1)

Constraint	(✔)	Ranking (1= most important)
Secure Land		
Water		
Availability		
Quality		
Cost		
Seed		
Availability		

Quality		
Cost		
Feed		
Availability		
Quality		
Cost		
Knowledge		
Technical		
Markets		
Equipment		
Price buyers are willing to pay		
Price of competing substitutes		
Others: Please specify		

16. Assuming prevailing market prices how much fish could you sell?

	Quantity (in kg, tons, or numbers)	Value of sales	Don't know (✔)
In a week			
In a month			
In a year			

17. What constraints, if any, do you see for **marketing your fish** (Can tick more than 1)

Constraints	(✔)
Poor demand	
Don't know demand	
Distance to market	
Market fees	
Low price	
Unstable price	
Poor transportation	
Competition with other producers of same fish	
Middlemen cut profit	
Cooperative / group is not performing	
Lack of post-harvest storage facility	
Insecurity	
Other:	

18. Do you engage in any non-cash exchange for your fish? (✔) Yes ___ No ___

If yes, what do you exchange your fish for?

(Items below can be modified to local conditions)

Exchange items	(✔)	Rank by importance
Cooking oil		
Maize		
Plantain		
Cassava		
Meat		
Other food items:		
Salt		
Local drinks		
Labour		
Others:		

18. Livelihood activities of fish producer (Can tick more than 1)

Activity	✔	Share of income (%)
Fish farming		
Wild fishing		
Agriculture		
Formal employment		
Casual employment		
Other please specify		

PRODUCER PERSONAL DATA

Name of fish producer(s): ____

Sex: Male: ( ) Female: ( )

Age in years: 0 –14 ( ), 15 – 24( ), 25 – 34( ), 35 – 44( ), 45-54( ), 55 – 64( ), >65 ( )

Marital Status (✔)

Married		Separated	
Single		Widowed	

Educational Status (✔)

No formal education		Secondary		Vocational	
Primary		Tertiary			

Farmer status (✔)

Farmer / food producer		Employed	
Business person		Retired	

Do you employ any persons on your farm: (✔):

Yes		No	

If yes:

	Gender			
	Male		Female	
	Permanent	Temporary	Permanent	Temporary
Number				
Age				

Household size (give numbers)

Adults	Male		Children	Male	
	Female			Female	

What is your annual income? ____________________

PLEASE THANK RESPONDENT AND CONCLUDE INTERVIEW